PB90-183575

Determining Soil Response Action Levels Based on Potential Contaminant Migration to Ground Water: A Compendium of Examples

Booz-Allen and Hamilton, Inc., Washington, DC

Prepared for:

Environmental Protection Agency, Washington, DC

Oct 89

U.S. Department of Commerce
National Technical Information Service
NTIS

BIBLIOGRAPHIC INFORMATION

PB90-183575

Report Nos: none

Title: Determining Soil Response Action Levels Based on Potential Contaminant Migration to Ground Water: A Compendium of Examples.

Date: Oct 89

Performing Organization: Booz-Allen and Hamilton, Inc., Washington, DC.

Performing Organization Report Nos: EPA/540/2-89/057

Sponsoring Organization: *Environmental Protection Agency, Washington, DC. Office of Emergency and Remedial Response.

Contract Nos: EPA-68-01-7376

Supplementary Notes: Also available from Supt. of Docs. Sponsored by Environmental Protection Agency, Washington, DC. Office of Emergency and Remedial Response.

NTIS Field/Group Codes: 68C, 50D, 48G

Price: PC A07/MF A01

Availability: Available from the National Technical Information Service,
Springfield, VA. 22161

Number of Pages: 145p

Keywords: *Ground water, *Environmental transport, *Soils, *Hazardous materials, Sites, Assessments, Water pollution control, Mathemtical models, Diagrams, Sludge disposal, *Superfund, *Cleanup, Case studies, Chemicals, Vadose zone.

Abstract: The document presents case studies illustrating various methods that have been used at Superfund sites to calculate soil cleanup levels based on the potential for hazardous constituents to migrate to and contaminate ground water. In addition, several methods for which case studies could not be identified have been included in a separate section. The purpose of the document is not to recommend specific methods; none of the methods or example analyses have been verified over the long-term. The compendium should be viewed as a resource which illustrates the importance of assessing the impact of soil contaminants on ground water and the effects various parameters have on contaminant migration through the unsaturated zone.

PB90-183575

United States
Environmental Protection
Agency

Office of Emergency and
Remedial Response
Washington DC 20460

EPA/540/2-89/057
October 1989

Superfund

EPA

Determining Soil Response Action Levels Based on Potential Contaminant Migration to Ground Water: A Compendium of Examples

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

EPA/540/2-89/057
October 1989

DETERMINING SOIL RESPONSE ACTION LEVELS BASED ON POTENTIAL CONTAMINANT MIGRATION TO GROUND WATER: A COMPENDIUM OF EXAMPLES

United States Environmental Protection Agency
Office of Emergency and Remedial Response
Washington, D.C. 20460

NOTICE

Development of this document was funded by the United States Environmental Protection Agency under contract No. 68-01-7376 to Booz, Allen & Hamilton Inc. It has been reviewed and approved by the Agency for publication as an EPA document.

The examples provided in this document are exclusively for reference. They are not designed to support or recommend any specific approach to determine soil response action levels, nor are they intended to be relied upon as guidance. The Agency reserves the right to act at variance with these procedures and methods at any time.

PREFACE

This document presents case studies illustrating various methods that have been used at Superfund sites to calculate soil cleanup levels based on the potential for hazardous constituents to migrate to and contaminate ground water. In addition, several methods for which case studies could not be identified have been included in a separate section. The purpose of this document is not to recommend specific methods; none of the methods or example analyses have been verified over the long-term. This compendium should be viewed as a resource which illustrates the importance of assessing the impact of soil contaminants on ground water and the effects various parameters have on contaminant migration through the unsaturated zone. Some of the simpler methods may be used as a screen during the initial phase of an investigation to determine the relative importance of this migration pathway. If it appears that the ground water pathway is significant, the descriptions of some of the more complex methods can be used to identify data needs pertinent to a more accurate assessment of this pathway.

When selecting or applying a model or methodology for a particular site, it is always advisable to obtain advice from experts in the field during the early stages of the investigation to ensure that data required by the method will be collected. Appendix A lists the current technical resources in the Regions -- the Ground Water and Engineering Forums members, and pertinent experts in the EPA laboratories. These individuals should be consulted during the scoping phase of an investigation to identify data needs early, and throughout the investigation as models are applied and evaluated.

TABLE OF CONTENTS

Page

Introduction 1

CASE STUDIES

Fate and Transport Methods
- Millcreek, PA (Freundlich) 14
- McKin, ME (SOCEM) 21
- Geiger/C&M Oil, SC (Summers) 27
- Pinette's Salvage Yard, ME (Unnamed). 33
- Pristine Inc., OH (Summers) 39
- Chemtronics, NC (SPPPLV) 43

Analytical Methods
- Hollingsworth, FL (Leachate Tests) 52

Generic Methods
- Woodbury Chemical, CO (Background Levels) 56
- Distler Farm, KY (Background Levels) 60
- Hocomonco Pond, MA (Visible Contamination) . . . 62
- Pacific Place, B.C. (Remediation Standards) . . . 65

METHODS

Fate and Transport Methods
- Contaminant Profile. 72
- AERIS 76
- Decision Tree 79
- Sewage Sludge Method 84

Generic Methods
- Designated Levels (CA) 90
- Acceptable Levels (NJ) 95
- MED 200. 97
- Technical Policy (WA) 99

BIBLIOGRAPHY 103

APPENDIX A - Technical Resources 114

APPENDIX B - Glossary of Terms 116

APPENDIX C - Leachate Extraction Tests 122

APPENDIX D - Partition-Coefficients and Water Solubility Values 128

APPENDIX E - Health-Based Criteria for Ground Water . . 138

APPENDIX F - Natural Migration Reduction Case Study . . 144

ACKNOWLEDGEMENTS

This document was developed by EPA's Office of Emergency and Remedial Response (OERR). Ms. Jennifer Haley of OERR's Hazardous Site Control Division (HSCD) was the EPA Project officer, under the direction of Mr. Bill Hanson, Branch Chief of Remedial Operations and Guidance Branch. Additional assistance was provided by:

Melanie Berger	Office of Waste Programs Enforcement
Marlene Berg	Office of Emergency and Remedial Response
Dominic DiGivlio	Office of Research and Development/Ada
Seong Hwang	Office of Research and Development
Barnes Johnson	Office of Policy, Planning, and Evaluation
John Matthews	Office of Reserach and Development/Ada
Ossi Meyn	Office of Solid Waste
Jon Perry	Office of Solid Waste
David Rosenblatt	U.S. Army/Ft. Detrick
Jim Ryan	Risk Reduction Engineering Laboratory
Paul Schumann	Office of Waste Programs Enforcement
Anne Sergeant	Office of Research and Development
Ken Skahn	Office of Solid Waste
Joe Slatter	U.S. Army/COE
Jeff Starn	EPA Region IV
Chittibabu Vasudevan	NY/DCE
Rick Watman	EPA/Region III
Ron Wilhelm	Office of Solid Waste and Emergency Response
Doug Yeskis	EPA Region V

Booz, Allen & Hamilton assisted OERR in the development of this document, in partial fulfillment of contract No. 68-01-7376. The Booz, Allen team included William Hannon, Stephen Zylstra, and Thomas Haynos.

INTRODUCTION

Purpose

This document presents examples of methods and models used to establish soil cleanup levels at Superfund sites where threats to ground water resources exist. It consists of case studies that illustrate how various methods have been applied at Superfund sites to derive soil cleanup levels based on the potential for hazardous constituents to migrate to and contaminate ground water. In addition, several methods for which case studies could not be identified are summarized in a separate section.

The primary purpose of this document is to demonstrate the importance of assessing the impact of soil contaminants on ground water and the effect various factors have on the unsaturated zone. Some of the simpler methods presented here might be used as a screen during the initial phase of site characterization to determine the relative importance of this pathway. If it appears that contaminant migration to ground water is a significant concern, more complex methods can be used to determine additional data needed to adequately assess this pathway.

Organization of Document

The following sections of the introduction describe the general process for assessing soil cleanup levels based on the potential for hazardous constituents to migrate to ground water and how this analysis fits into the overall remedial investigation and feasibility study for a site. An overview of the primary factors affecting pollutant migration in the subsurface is provided to aid in understanding the reasons particular parameters are included in the case studies that comprise Section 2 of this document. A glossary of commonly used terms in soil and ground water disciplines also is provided following the introductory pages.

The major portion of this document, Section 2, provides examples of various methods and models as they were applied. Individual sites are described with respect to their physical characteristics and known contaminants. The methods used to derive soil cleanup levels at these sites are described along with the site-specific conditions that prompted their use. Figures 4 and 5 at the beginning of Section 2, summarize the site-specific data requirements and contaminants of concern for the sites included to facilitate identification of those sites with characteristics of interest.

Section 3 discusses additional methods and models for which case studies could not be identified. Several of these models were designed as starting points for an investigation rather than for determining the final soil cleanup levels. Also documented within the model abstracts, are the original literature source for reference.

Finally, the appendices of the compendium are designed to provide the reader with abstracts of some of the available leachate tests currently being applied; some literature values and methods to determine partition coefficients and water solubility values; information concerning health-based criteria for ground water; and a case study that describes a situation where natural attenuation of contaminant concentrations resulted in the achievement of protective soil cleanup levels.

General Principles of Application

As illustrated in Figure 1, the level of soil remediation required will depend on many site-specific factors, as well as the hazardous constituents identified and transport processes involved, and the degree of public exposure at the site. Therefore, the methods and models used as tools in the analysis of contaminant migration to ground water will vary from one site to another depending on the unique site characteristics and the chemicals involved. In general, the major milestones in the determination of soil cleanup levels can be depicted as shown in Figure 2.

Like the RI/FS process as a whole, the method for determining soil cleanup levels based on potential contaminant migration to ground water is iterative, with each of several stages producing an increasingly accurate picture of actual contaminant migration. Because the data available at different phases in the RI/FS varies, estimates of soil cleanup levels may be made using different methods, models, and approaches, depending on the time at which the analysis occurs. Once contaminant migration to ground water is determined to be a pathway of concern at the site, there are three primary methods for improving the accuracy of projected migration: obtaining additional data, using more refined data collection techniques, using more sophisticated models. A combination of these techniques may be appropriate.

During the scoping phase, limited field data will be available and an initial estimate of soil cleanup levels might be made using literature values for model parameters. For example, literature values of soil/water partition coefficients might be used in the initial estimate. This estimate could be refined by analyzing select subsurface samples for organic carbon content and using this information to calculate the partition coefficient from literature values of the octanol/water partition coefficient (generally considered to be

FIGURE 1
Environmental Transfer of Hazardous Constituents

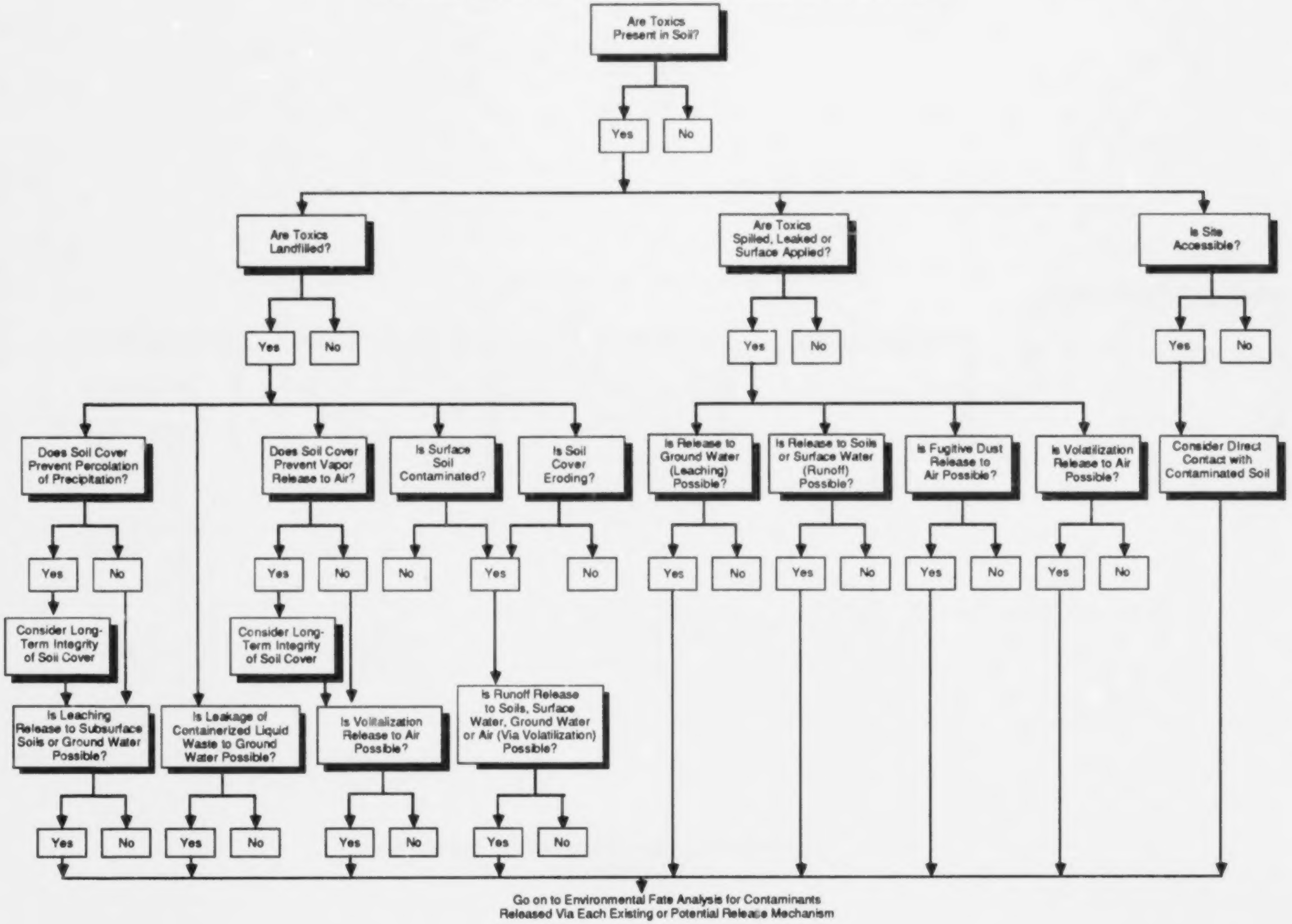
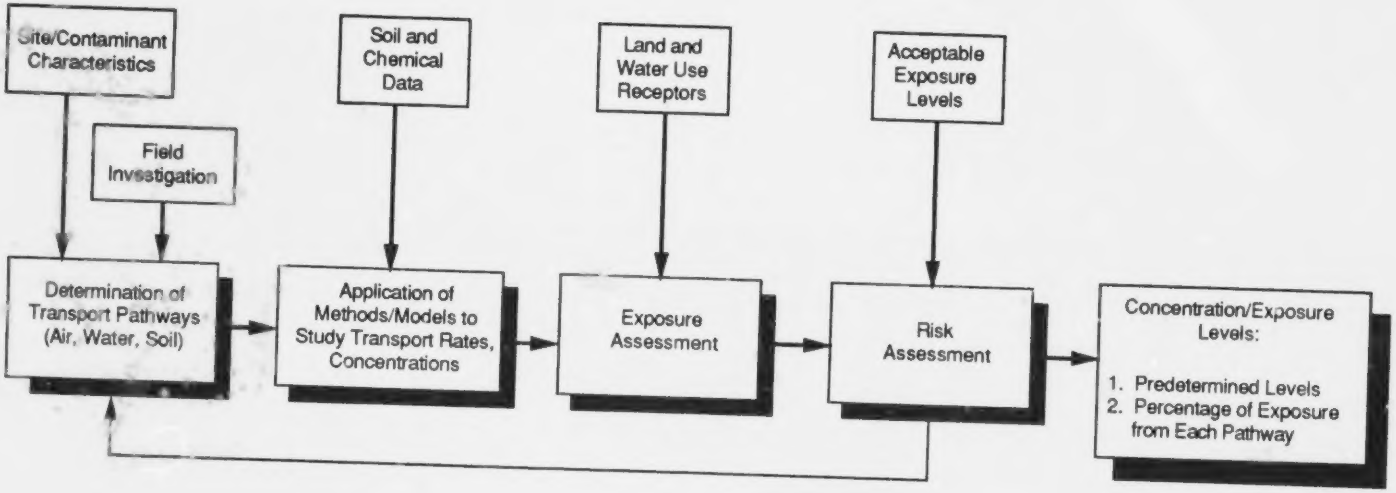

Are Toxics Present in Soil?
Yes
No
Are Toxics Landfilled?
Yes
No
Are Toxics Spilled, Leaked or Surface Applied?
Yes
No
Is Site Accessible?
Yes
No
Does Soil Cover Prevent Percolation of Precipitation?
Yes
No
Consider Long-Term Integrity of Soil Cover
Is Leaching Release to Subsurface Soils or Ground Water Possible?
Yes
No
Is Leakage of Containerized Liquid Waste to Ground Water Possible?
Yes
No
Does Soil Cover Prevent Vapor Release to Air?
Yes
No
Consider Long-Term Integrity of Soil Cover
Is Volitalization Release to Air Possible?
Yes
No
Is Surface Soil Contaminated?
No
Yes
Is Soil Cover Eroding?
No
Is Runoff Release to Soils, Surface Water, Ground Water or Air (Via Volatilization) Possible?
Yes
No
Is Release to Ground Water (Leaching) Possible?
Yes
No
Is Release to Soils or Surface Water (Runoff) Possible?
Yes
No
Is Fugitive Dust Release to Air Possible?
Yes
No
Is Volatilization Release to Air Possible?
Yes
No
Consider Direct Contact with Contaminated Soil
Go on to Environmental Fate Analysis for Contaminants Released Via Each Existing or Potential Release Mechanism

FIGURE 2
Process for Determining Soil Cleanup Levels


Site/Contaminant Characteristics
Field Investigation
Soil and Chemical Data
Land and Water Use Receptors
Acceptable Exposure Levels
Determination of Transport Pathways (Air, Water, Soil)
Application of Methods/Models to Study Transport Rates, Concentrations
Exposure Assessment
Risk Assessment
Concentration/Exposure Levels:
1. Predetermined Levels
2. Percentage of Exposure from Each Pathway

less affected by site-specific considerations than the soil/water partition coefficients). The uncertainty in the estimation might be further reduced by collecting and analyzing soil cores from the site to calculate actual partition coefficients or other site-specific characteristics.

The quality of the data itself also will affect the accuracy of estimates of contaminant migration to ground water. An iterative process in which data collection techniques are continually improved should be used during the remedial investigation to accurately assess the significance of critical exposure pathways. For example, field analyses and geophysical techniques may be used in the initial estimate of contaminant migration with more detailed laboratory analysis of select samples conducted as the locations and parameters of concern are identified.

As available data increase, it becomes possible to use increasingly complex models. A determination of the most appropriate model should be based on its ability to incorporate factors of particular concern for the site under investigation, as well as the resources available to the site manager. There is always a trade-off between the amount and accuracy of information provided by the application of sophisticated models, and the resources available to apply the model (e.g., time, expertise, input data, computing facilities).

Once a model has been applied using the initial data, a sensitivity analysis is performed to determine if reassessment of the exposure pathway is required. The results of a sensitivity analysis will help identify any needs for additional site-specific data. Where possible, actual monitoring data should be used in combination with calculations or model projections to show either a lack of contaminant movement to ground water or to characterize the plume in the unsaturated or saturated soil zones.

Following remedy implementation, verification sampling is essential to ensure the accuracy of the predicted concentrations. Where it is uncertain that levels have been attained, contingency measures may be warranted. These may include land use restrictions, site re-evaluation (after some time period), or a more aggressive "fallback" remedy if actual contaminant migration is greater than predicted. Some statistical methods that may be used to verify attainment of specified cleanup levels have been described in the document entitled Methods for Evaluating the Attainment of Cleanup Standards (EPA-230/02/89-042). The Superfund program is currently evaluating the appropriate use of these statistical methods at Superfund sites.

More detailed discussions of the overall RI/FS process and data collection refinement can be found in the Guidance for Conducting Remedial Investigations and Feasibility Studies (EPA-540/G-89/004) and the Data Quality Objectives Development Guidance (OSWER Dir. 9355.0-7A).

Transport Processess Pertinent to Evaluating Migration to Ground Water

The schematics in Figure 3 indicate the hydrogeochemical processes affecting pollutants and their associated environmental transfer media. The fate and transport factors affecting subsurface contaminant migration processes within this scheme can be broadly classified as physical, chemical, and microbial. These processess and the factors affecting their relative significance at a site are listed in Table 1. The variety and quantity of such factors make the exposure route determination more difficult for ground water than for other exposure pathways. Consequently, arriving at an acceptable cleanup level based on potential migration to ground water may warrant a detailed characterization of the site, needs assessment, and careful selection of analytical tools.

Transport and speciation models rely on the quantification of relationships between specific parameters and variables to simulate the effect of natural processes. Therefore, a close match between the natural processes at the site and those of the selected model must exist if the modeling exercise is to provide satisfactory results. For example, a model that does not consider attenuation of chemicals in the unsaturated zone would not be appropriate for a site where the depth to ground water is considerable.

Transport processes strongly depend upon chemical speciation. The simplest approach to estimating the concentration of a hazardous constituent is to assume it behaves conservatively (i.e., does not undergo reaction). Rigorious models generally include consideration of transformation, transport, and speciation. In this approach, the rate constant for first-order attenuation in the unsaturated zone and the partition coefficient between solid, liquid, and gas phases must be considered. The inclusion of degradative processes such as biodegradation and hydrolysis considerably increases the chemical and environmental data required to model the fate of a compound, and consequently, the evaluation of hazard to human health and the environment. Where such degradative processes are suspected, a more refined assessment becomes necessary.

FIGURE 3
Media Involved in a Typical Superfund Site
Waste Impoundment

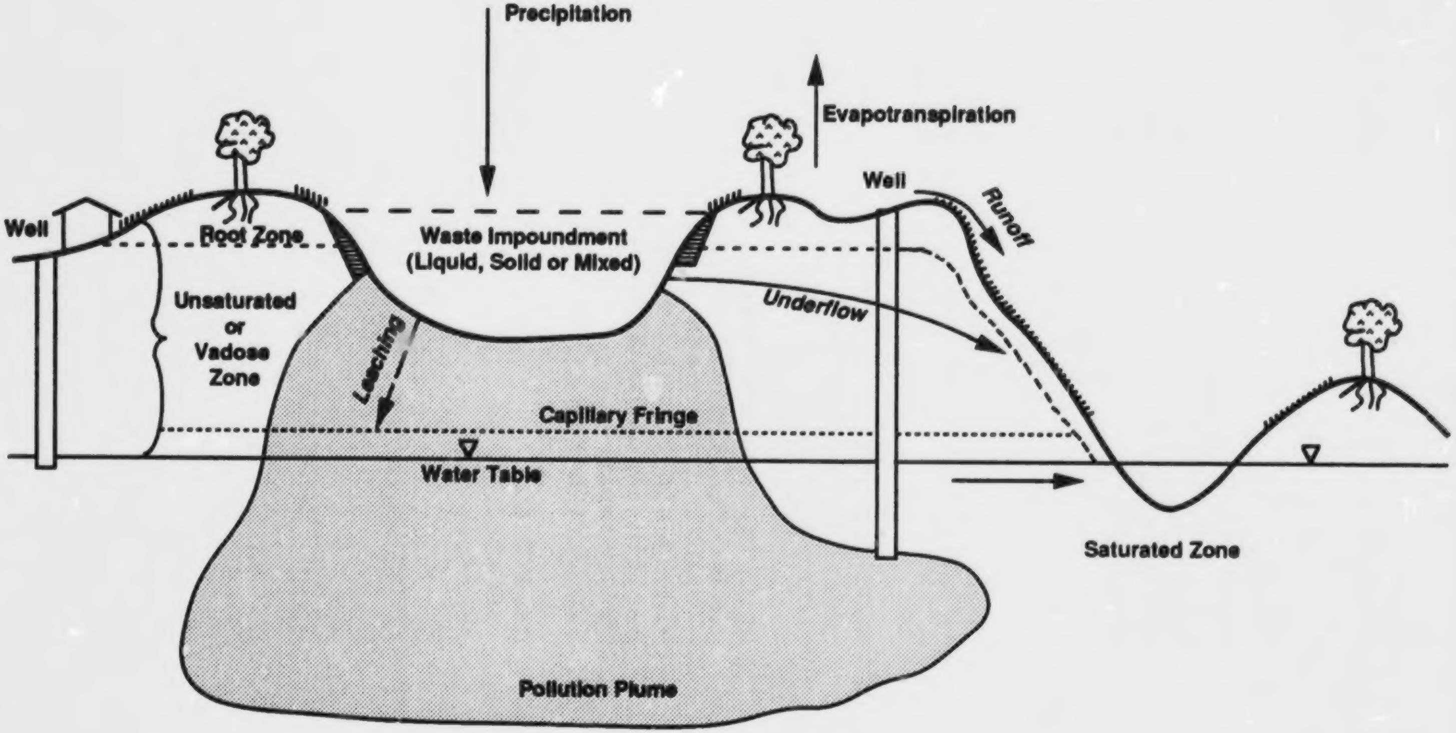

Precipitation
Evapotranspiration
Well
Well
Runoff
Root Zone
Waste Impoundment
(Liquid, Solid or Mixed)
Unsaturated
or
Vadose
Zone
Underflow
Leaching
Capillary Fringe
Water Table
Saturated Zone
Pollution Plume

TABLE 1
Fate And Transport Processes Affecting Subsurface Migration

Category	Process	Factor Affecting Process
Physical	Advection Dispersion Flow in fractures Diffusion Precipitation Dissolution	Topography Climate Precipitation Soil type Vegetative cover Depth to ground water Soil permeability Soil void ratio Soil-moisture characteristics Geology Hydrology Morphology
Chemical	Partitioning -sorption/desorption -ion exchange -volatilization Equilibrium speciation -acid/base equilibration -organic complexation -inorganic complexation Abiotic transformation -hydrolysis -oxidation/reduction	Physical, chemical properties of contaminants Geology
Microbial	Oxidation/ reduction and hydrolysis	Geology Contaminants Microbial environment

In summary, the prediction of contaminant transport and transformation involves the following six steps:

1. Determination of fate-influencing processes (i.e., transport parameters, partition coefficient)
2. Delineation of environmental compartments
3. Representation of soil/hydrogeologic processes
4. Mathematical representation of speciation processes (i.e., acid-base, sorption)
5. Mathematical representation of transport and transformation processess (i.e., precipitation, dissolution, solubility limits, advection for dissolved or sorbed phases)
6. Determination of contaminant load and mode of entry into the environmental media.

Steps 1 through 3 can be formulated during the scoping phase of a site investigation at which point an initial determination of the pathways of concern are made. Steps 4 through 6 can be developed and refined iteratively throughout the RI/FS. Three levels of refinement in assessing the pollutant may be considered. These are, in order of increasing complexity:

1. Consider the contaminant as a conservative substance
2. Consider the transport and speciation processes
3. Consider transformation, transport, and speciation processes.

In conclusion, to accurately predict the fate of contaminants, the user must have a clear idea of which processes act on the contaminant, and of those, which are dominant. Summary exhibits 4 and 5 may be used concurrently as a quick reference data source to identify sites with specific hazardous constituents or processes. Exhibit 4 represents a summary of site-specific data requirements and processes used to evaluate hazardous constituent migration through the unsaturated zone at the 11 CERCLA sites documented in this compendium. Although this table comprehensively summarizes the requirements and processes used within the case studies, it should not be viewed as an exhaustive list of parameters affecting hazardous constituent migration and soil response action level evaluation and selection. Exhibit 5 compliments the site-specific data requirements summary by tabulating the hazardous constituents, identified as contaminants of concern within the case studies. This tabulation may assist in reviewing sites with similar constituents to identify the decision making process used to establish soil response action levels at these sites.

These exhibits are immediately followed by Section 2, which presents case studies illustrating various methods that have been used at Superfund sites to calculate soil cleanup levels based on potential migration to ground water.

FIGURE 4
Site-Specific Data Requirements
and Processes

SITE NAME, STATE	DATA REQUIREMENTS																		PROCESSES									
	Partition Coefficient	Concentration At Receptor Well	Health-based Level	Compliance Point	Amount Of Rainfall/Year	Saturated Zone Thickness	Ground Water Velocity	Concentrations/ Unsaturated Zone	Volumetric Flow Rate	Horizontal Area Of Pond Or Spill	Thickness Of Aquifer	Background Concentrations (Ground Water, Soil)	Void Fraction (GWV/VOS)	Organic Carbon Fraction	Acceptable Daily Intake For Each Contaminant	Leachate Analysis	Visible Identification	Future Land Use	Partitioning	Transverse Dispersivity	Percolation	Sorption	Infiltration	Dilution	Degradation	Mobility	Solubility	Hydraulic Conductivity
Millcreek, PA	●	●	●	●	●	●	●			●									●	●	●	●						
McKin, ME	●		●	●		●	●	●						●					●	●	●	●					●	●
Geiger/C&M Oil, SC	●							●	●	●	●	●	●	●					●			●	●					
Pinette's Salvage, ME	●		●		●	●	●	●	●	●				●					●		●	●		●				●
Pristine, OH	●						●	●	●	●	●	●	●	●					●			●	●					
Chemtronics, NC			●	●	●				●			●			●									●	●			
Hollingsworth, FL			●									●				●					●	●	●			●	●	
Woodbury Chemical, CO			●									●																
Distler Farm, KY												●																
Hocomonco, MA																	●											
Pacific Place, B.C.																		●										

FIGURE 5
Contaminants of Concern

SITE NAME, STATE	INORGANICS								EXTRACTABLES													DIOXINS		PESTICIDE/PCB					VOLATILE ORGANICS									
	Arsenic	Chromium	Copper	Iron	Lead	Manganese	Mercury	Nickel	2 - Chlorobenzalmalononitrile	Phthalates	PNAS	Benzo(A)Pyrene	Anthracene	Chrysene	Pyrene	Fluoranthene	Phenanthrene	Naphthalene	Isophorone	Phenol	Picric Acid	2,3,7,8 - TCDD	Dibenzofuran	PCB	Alpha - BHC	Aldrin	DDT	Dieldrin	1,1 - DCA	1,1,1 - TCA	TCE	Chloroform	Benzene	Vinyl Chloride	Toluene	Acetone	1,2 - DCE	PCE
Millcreek, PA			●	●	●					●	●									●				●						●	●			●				
McKin, ME					●																										●							
Geiger/C&M Oil, SC		●			●		●																	●							●				●			
Pinette's Salvage, ME																								●									●					
Pristine, OH											●											●				●	●	●	●		●	●	●				●	
Chemtronics, NC		●			●				●												●														●			
Hollingsworth, FL			●		●			●																														
Woodbury Chemical, CO				●		●																			●											●		
Distler Farm, KY	●	●			●					●								●	●												●		●		●			●
Hocomonco, MA	●	●			●							●	●	●	●	●	●	●					●															
Pacific Place, B.C.	●	●	●		●		●	●				●	●	●	●	●		●		●				●			●						●		●			

FATE AND TRANSPORT METHODS

Site Name: **Millcreek, PA**

Contaminants:

PCBs	Copper
PNAs	Lead
Phthalates	1,1,1-Trichloroethene
Phenols	Vinyl Chloride
Manganese	Iron

Depth to Ground Water: Not provided in documentation.

Data Requirements:

- Concentration at receptor well or compliance area (health-based level or ground water quality goal)
- Lateral plume thickness
- Distance of compliance point from source
- Transverse dispersivity
- Amount of rainfall per year at site
- Total area contaminated with specific contaminant
- Saturated zone thickness
- Ground water velocity
- Lateral source length or lateral extent of source area
- Dry weight concentration of a nonionic organic compound in soil
- Equilibrium pore space aqueous concentration

Method: **Freundlich Equation** - This method is designed to evaluate organic compounds in the unsaturated zone. In the following case study, it is used in conjunction with the VHS model to determine estimated dry soil contaminant concentrations which contribute to elevated ground water contaminant levels (i.e., above ground water quality goals).

Source: Millcreek, PA, Record of Decision, Appendix B, 1985.

Case Study: Millcreek, PA

Waste Description: The site contamination was found in soil, sediments and ground water. Specific contaminant concentrations include:

- PCBs (31 mg/kg)
- PNAs (539 mg/kg)
- Phthalates (72 mg/kg)
- Volatiles (6 mg/kg)
- Copper (20,500 mg/kg)
- Lead (2,375 mg/kg)
- Phenols (7 mg/kg)

Soil Type: Surficial and near-surface natural deposits consist of alternating layers of fine sands and silts with occasional clayey or gravely zones. The thickness of these deposits ranges from 15 feet to 28 feet.

Depth to Ground Water: Ground water at the site occurs both in water table and semi-confined conditions. The water table extends into the fill throughout the wet portions of the year. The depth to ground water varies throughout the site. An average depth was not provided.

Method Description: The Freundlich method is designed for use with organic compounds. It is used to determine a dry soil contaminant concentration which would elevate ground water contaminant levels above ground water quality goals (e.g., MCLs). A dry soil contaminant level is calculated for each individual or group of organic contaminants of concern. At this site, the Freundlich Equation was used in conjunction with the VHS model ground water fate and transport equation, which is referred to as the RAPID assessment model. (Refer to the McKin Case Study for further information pertaining to the VHS model.) The Freundlich Equation is:

$$Q_e = (K_d)(C_e)(1/n) \qquad (1)$$

where: Q_e = the dry weight concentration of a nonionic organic compound in soil (mg/kg)

C_e = the equilibrium pore space aqueous concentration (mg/l)

n = an experimentally derived exponential adjustment factor to the adsorption isotherm

K_d = soil:water partition coefficient

In order to use the Freundlich equation, a value for C_e must be derived. This requires several calculations. The first calculation involves the VHS model equation or the RAPID assessment model:

$$C_o = \frac{C}{\mathrm{erf}\,\dfrac{Z}{2(A_t \cdot X)^{1/2}}\;\; \mathrm{erf}\,\dfrac{Y}{4(A_t \cdot X)^{1/2}}} \qquad (2)$$

where: C_o = original ground water concentration at the source area
C = concentration at receptor well or compliance area
Z = saturated zone thickness
X = distance of compliance point from source
Y = width of lateral extent of source
A_t = transverse dispersivity
erf = error function

By using a health-based level or ground water quality value such as an MCL for C, the desired concentration in the ground water directly beneath the contaminant source (C_o) that correlates with this value can be calculated. At this site, the following values were used to established the PNA cleanup level:

Z = 16 feet
A_t = 13 feet
C = 0.029 ug/l (10^{-6} Unit cancer risk factor direct ingestion level)
X = 1,000 feet
Y = 2,400 feet

The equation derived a C_o value of 0.037 ug/l.

After the original source concentration (C_o) is obtained, the percolation rate through the unsaturated zone is calculated.

$$\text{Percolation Rate} = (\text{percolation})(\text{area}) \qquad (3)$$

where: percolation = amount of rainfall per year at site (in/year)

area = total area of site contaminated with specific contaminant (ft^2)

The values used at the Millcreek site were:

$$[(11.15 \text{ in/year})\ (1 \text{ foot}/12 \text{ in})]\ (1{,}215{,}000 \text{ ft}^2)$$

$$= 1{,}128{,}938 \text{ ft}^3\text{/year or } 9{,}743{,}864 \text{ liters/year}$$

The next calculation required to estimate migration is the lateral ground water flow (LGWF) equation:

$$\begin{aligned} \text{LGWF} = {} & \text{saturated thickness (ft)} \\ & \times \text{ ground water velocity (ft/year)} \\ & \times \text{ lateral source length (ft)} \end{aligned} \qquad (4)$$

For the Millcreek site the following calculations were performed:

$$(16\ \text{ft})\ (60\ \text{ft/year})\ (2{,}400\ \text{ft}) = 2{,}304{,}000\ \text{ft}^3\text{/year}$$
$$\text{or } 19{,}885{,}824\ \text{liters/year}$$

The LGWF is then added to the percolation rate to get the total flow in the saturated zone underlying the contaminated area.

$$\text{Total Flow} = \text{LGWF} + \text{Percolation Rate} \qquad (5)$$

Total Flow equals:

(9,743,864 + 19,885,824) liters/year = 29,629,688 liters/year

Next, to determine the annual mass of contaminant leaching from the unsaturated zone (X) the following relationship is used:

$$\frac{X}{\text{Total Flow (liters/year)}} = C_o\ (\text{ug/liter}) \qquad (6)$$

To cause a PNA contaminant level of 0.037 ug/l in the saturated zone underlying the contaminated area would require the following:

$$\frac{X}{29{,}629{,}688\ \text{liters/year}} = \frac{0.037\ \text{ug}}{\text{liter}}$$
$$= 1.1\ \frac{\text{grams}}{\text{year}}$$

The next step in this process is to determine the average unsaturated pore space aqueous concentration which would cause the C_o in the saturated zone directly below the site to exceed the calculated value derived earlier. This is estimated by dividing the annual mass of the contaminant escaping from the unsaturated zone by the percolation rate.

$$C_o = \frac{\text{annual mass (grams/year)}}{\text{percolation through unsaturated zone}} \qquad (7)$$

$$\text{or} \quad \frac{1.1\ \text{grams/year}}{9{,}743{,}864\ \text{liters/year}} = 1.13\ \text{ug/l}$$

Next, K_{oc} and F_{oc} values are determined. Using K_{oc} and F_{oc} tables, values of 144,561 and 0.018, respectively, were selected. Using these values in equation (1) and a value of 1.13 ug/l for the adjustment factor to the adsorption isotherm, $Q_e = (Kd)(C_e)(1/n)$, yielded the following:

$$Q_e = (144{,}561)\ (0.018)\ (1.13)$$
$$= 2.94 \text{ mg/kg for a } 10^{-6} \text{ risk level}$$

The resultant dry soil concentration is the suggested level of soil cleanup that would derive a contaminant concentration in compliance with a ground water quality goal or a health-based value at a receptor well.

The primary limitations to the Freundlich equation include the two assumptions that must be made. The model assumes completely reversible adsorption, which may never be achieved. It also assumes the rate of adsorption and desorption realize instantaneous equilibrium. Both of these assumptions are under debate at this time in the scientific community. Because the (n) values used to obtain the adjustment factor to the adsorption isotherm are experimentally derived and can be different for different ranges of the Freundlich isotherm, they are difficult to determine. Therefore, they were assumed to be unity, thus making the isotherm linear. The time investment required to derive (n) also may be considered a limitation.

Data Requirements/Processes Addressed:

- Concentration at receptor well or compliance area (health-based level or ground water quality goal)
- Lateral plume thickness
- Distance of compliance point from source
- Transverse dispersivity
- Amount of rainfall per year at site (in/year)
- Total site area contaminated with specific contaminant (ft^2)
- Saturated zone thickness (ft)
- Ground water velocity (ft/year)
- Lateral source length or lateral extent of source area (ft)

Site-Specific Cleanup Goals: The following is a list of the derived soil cleanup levels for the contaminants found at the site using the method described above. Also included are the established acceptable contaminant concentration levels at a receptor well, as well as the basis for which these levels were determined. It was assumed that the receptor well location is onsite in order to ensure cleanup of the entire plume.

Compound	Soil Cleanup Criteria (ug/l)	Concentration at Receptor Well (ug/l)	Basis for Cleanup Level
PNAs	2940	0.0024	10^{-6} UCR
PCBs	116	0.005	background levels
TCE	<10	2.8	10^{-6} UCR
1,2-DCE	594	70.0	HA
1,1,1-TCA	540	22.0	HA
1,1-DCA	760	460.0	AIC
EDC	<10	0.95	10^{-6} UCR
1,1-DCE	<10	0.24	10^{-6} UCR
Chloroform	<10	0.19	10^{-6} UCR
Phthalates	338,000	3.0	aquatic life RL
Phenols	9,000	300.0	taste threshold

HA = Health Advisory, Office of Drinking Water, 1985
UCR = 10^{-6} unit cancer risk factor

Site-Specific Method Application: In order to establish safe soil levels to prevent future contamination of ground water, the following steps were followed:

- Determine receptor location - Established by examining each potential receptor location and the associated toxicological effects of contaminants. The receptor pathways were identified as direct, future down-gradient human ingestion of ground water, chronic effects on aquatic life in surface water due to contaminated ground water, and human and wildlife ingestion of aquatic life in the stream adjacent to the site.

- Determine acceptable contaminant concentrations at receptor location - Determined by examining the most current EPA criteria, health advisories, and appropriate toxicological literature.

- Determine source location - Accomplished by examining soil contamination patterns.

- Determine ground water contaminant concentrations at the source which would bring the contaminant concentration above acceptable levels at the receptor - Accomplished by using an appropriate ground water model called the RAPID assessment model, also known as the SOC[illegible]M I model.

- Determine soil concentrations which are based on the ground water contaminant levels at the source that would result in concentration levels below acceptable limits at the receptor - Involves establishing an unsaturated zone contaminant flow model. At this site, a model for the organics was developed using the Freundlich equation isotherm, as well as some additional calculations and measurements such as annual percolation, area of contamination, ground water flow velocity, thickness of the saturated zone, and total organic carbon content of onsite soil. The acceptable ground water contaminant levels were designed to protect human health through ingestion of ground water, through consumption of aquatic life, and to protect aquatic life. Levels were established separately in an additive manner for carcinogens and noncarcinogens. For carcinogens with a potential for direct human ingestion, a 10^{-6} unit cancer risk was deemed acceptable. Health advisories from the Office of Drinking Water, September 1985, and MCLs also were used to establish acceptable contaminant levels. This methodology was applied to all compounds except PCBs, which were set at a level based on background PCB concentrations in the ground water. Health-based levels were not used because they were below the background concentrations.

Site Name: **McKin, ME**

Contaminants: Trichloroethylene
Lead

Depth to Ground Water: 35 feet

Data Requirements:

- Maximum allowable downgradient concentrations
- Saturated zone thickness
- Distance from site boundary to receptor
- Lateral extent of plume at solid waste boundary
- Transverse dispersivity
- Concentration of contaminants in soil
- Concentration of contaminants in ground water directly below the source
- Soil:water partition coefficient

Method: **SOCEM** - This method is a version of the Vertical and Horizontal Spread (VHS) model equation which includes the use of site-specific data. Unlike the RCRA delisting procedure, SOCEM also incorporates a method for determining a soil cleanup level that corresponds to the maximum allowable contaminant level in ground water at some downgradient receptor.

Source: CH_2M Hill; Soil Contaminant Evaluation Methodology (SOCEM). In Guidance on Remedial Actions for Contaminated Soils at CERCLA Sites (Draft); and "Groundwater," May-June edition, 1985.

Case Study: McKin, ME

Waste Description: Removal operations have occurred at the site, including removal of pumpable liquid wastes from above ground tanks and drums, and disposal of all onsite barrels, containers, above ground tanks and drums. The remaining contamination problems are onsite surface and subsurface soil contamination and offsite ground water contamination. Soil contamination is located in several "hot spots" and contain primarily volatile organics and some metals. Trichloroethylene was found in concentrations up to 1,500 ppm. The depth of contamination was found at 6 feet or less in some locations and to at least 12 feet in other areas. Additionally, 16 buried drums were found onsite.

Soil Type: The site area is located on a relatively permeable glacial outwash plain comprised of stratified sand, gravel, and boulders overlying heavily weathered granitic bedrock.

Depth to Ground Water: The top of the ground water table is estimated to be at an average depth of 35 feet.

Method Description: SOCEM incorporates the ground water fate and transport equation from the Vertical and Horizontal Spread (VHS) model. The model was used as part of the RCRA hazardous waste evaluation procedure to determine if contaminant concentrations in leachate from a hazardous waste landfill warrant classifying it as a hazardous substance. Values for factors used in the VHS equation, when applied as a delisting model were estimated, taken from scientific literature, or assumed to be a specific value for every site. For instance, the value for the distance from the waste boundary to the receptor location was designated as 500 feet. SOCEM is a version of the VHS model equation which includes the use of site-specific data. Unlike the RCRA delisting procedure, SOCEM also incorporates a method for determining a soil cleanup level that corresponds to the maximum allowable contaminant level in ground water (e.g., water quality criteria) at some downgradient receptor.

To use SOCEM, the first step is to calculate the allowable concentration in the ground water directly below the contaminated source. Given the maximum allowable concentration, the initial source concentration can be calculated by the VHS equation (described in the Millcreek Case Study).

After deriving the initial source concentration (C_o) by using the VHS equation, the next step is to convert this maximum allowable ground water contaminant concentration to an allowable soil contaminant concentration. This is done by using a partition coefficient (K_d) defined by the following, where $C_o = C_{water}$:

$$K_d = \frac{C_{soil} \ \ (ug/g)}{C_{water} \ \ (ug/ml)} \qquad (1)$$

(Several other methods to determine K_d values are described in Appendix D.) Finally, the required soil cleanup concentration level can be determined by multiplying the allowable concentration in the ground water directly below the site by the partition coefficient:

$$C_{soil} = (C_{water}) \times (K_d) \qquad (2)$$

Data Requirements/Processes Addressed:

- Maximum allowable downgradient concentration
- Saturated zone thickness
- Distance from site boundary to receptor
- Lateral extent of the plume at the solid waste boundary
- Transverse dispersivity
- Concentration of contaminants in soil
- Concentration of contaminants in ground water directly below the site
- Soil:water partition coefficient
- Effective porosity
- Hydraulic conductivity
- Hydraulic gradient
- Longitudinal dispersivity
- Downgradient plume concentration
- Ground water velocity

Site-Specific Cleanup Goals: Using trichloroethylene (TCE) as an indicator chemical, the SOCEM model was used to predict a soil cleanup level of 0.1 ppm. This level was selected to prevent downgradient ground water contamination from exceeding the water quality criteria level of 28 ppb for TCE.

Site-Specific Method Application: Several analytical solution models were considered at the McKin site to estimate the contaminant concentrations in ground water at the contaminant source and at the location of the nearest potential receptor. TCE was chosen as the indicator compound at the site. This selection was based on the onsite concentration of TCE, its frequency of occurrence, its physical and biological characteristics (i.e., solubility, K_{OC}, and biodegradation susceptibility), and its observed concentration relative to the USEPA Preliminary Protective Concentration Limits (PPCL). These are guideline levels that should not be exceeded and are based on long-term, low levels of exposure through ingestion of potable water (Salee, 1984).

The SOCEM model was chosen as the most appropriate to be applied because it predicted an onsite ground water TCE concentration (117 ppm) similar to an actual onsite measured value from an onsite monitoring well (130 ppm). (Refer to Exhibit 1 for a list of the parameters used in deriving the predicted concentration.)

Additional support is given to this predicted concentration because the value of 117 ppm is approximately one-tenth of the maximum solubility of TCE in water, which is 1,100 ppm. In Transport of Organic Contaminants in Groundwater by MacKay et al., the author states that organic compounds are rarely found in ground water at concentrations approaching their solubility limits. The observed concentrations are usually found to be a factor of 10 lower than their solubility limits.

The results from this predictive stage indicate that SOCEM is an acceptable model for application at the McKin site. The next step in the process is to estimate the ground water contaminant concentration at the source that results in a downgradient ground water contaminant concentration that would not exceed the water quality criteria level of 28 ppb for TCE. Using the SOCEM model and the site-specific parameters including a downgradient distance of 200 feet (the distance to the site boundary), a ground water TCE concentration of 0.096 ppm at the contaminant source was predicted.

With these data, the contaminated soil cleanup level that corresponds to the allowable concentration in the ground water beneath the source can be estimated. Applying the partition coefficient value, equation (2) $C_{soil} = (C_{water})(K_d)$ described in the SOCEM model, a soil with a five percent organic matter content yields a soil TCE concentration of 0.1 ppm.

Exhibit 1
MCKIN PARAMETERS

Input Parameter	Value
Q_o = Contaminant Flow Rate	$125 \frac{gal}{yr} = 16.7 \frac{ft^3}{yr}$
B = Saturated Thickness	15 ft
n_e = Effective Porosity	0.25
K = Hydraulic Conductivity	$7\text{x}10^{-4} \frac{cm}{sec} = 724.3 \frac{ft}{yr}$
i = Hydraulic Gradient between the site and well B-1	$\frac{250'-224'}{800'} = 0.0325$
V = Ground Water Velocity = $\frac{Ki}{n_e}$	$\frac{(723.4)(0.0325)}{0.25} = 94.0 \frac{ft}{yr}$ $= 0.26 \frac{ft}{day}$
A_l = Longitudinal Dispersivity	10m (32.8 ft)
A_t = Transverse Dispersivity	1m (03.3 ft)
C = Downgradient Plume Concentration at well B-1	28 ppb (16 ppm - predictive test)
X = Distance from the site to Well B-1	200 ft (800 ft - predictive test)

Specifically:

$$0.09\ \frac{ug}{ml} \times 1.1\ \frac{ml}{g} = 0.11\ \frac{ug}{g} \text{ or } 0.11\ \text{ppm}$$

Therefore, the model predicts that a site boundary TCE concentration of 96 ppb can be reached by achieving a TCE soil cleanup level of 0.1 ppm.

Site Name: Geiger/C&M Oil, SC

Contaminants: PCB-Aroclor 1254
Toluene
Trichloroethylene
Lead
Mercury
Chromium

Depth to Ground Water: 2 feet

Data Requirements:

- Volumetric flow rate of infiltration (soil pore water) into aquifer (ft^3/day)
- Darcy velocity in aquifer
- Ground water seepage velocity
- Void fractions (ground water volume/volume of solid)
- Horizontal area of contamination
- Volumetric flow rate of ground water (ft^3/day)
- Thickness of aquifer
- Background contaminant concentration in aquifer (ug/l)
- Contaminant concentration in the infiltration (ug/l)

Method: **Summers Model** - This model assumes that a percentage of rainfall at the site will infiltrate and desorb contaminants from the soil based on equilibrium soil:water partitioning. Using ground water modeling, the soil cleanup level is calculated from the original soil concentration, the concentration of the infiltrating water, and an equilibrium coefficient.

Source: Summers, K.S., Gherini and C. Chen, Tetra Tech Inc., Methodology to Evaluate the Potential for Groundwater Contamination from Geothermal Fluid Release, EPA-600/7-80-117, 1980, as modified by EPA Region IV.

Case Study: Geiger/C&M Oil, SC

Waste Description: Contaminants of concern found in the surface soil consist of the following:

Organics	Metals
PCBs-Aroclor 1254 (4,000 ppb)	Lead (740 ppm)
TCE (230 ppm)	Mercury (1.3 ppm)
Toluene (460 ppb)	Chromium (1,100 ppm)

The depth of soil contamination is estimated to be five feet in the oil-stained area and one foot in other areas of the site.

Soil Type: Soils at the site are predominately sandy throughout their profile, but contain silt and interspersed mud lenses.

Depth to Ground Water: The average ground water lies at a depth of two feet below the surface. Depth to the water surface varies seasonably, reaching a minimum of one foot below the ground surface. The uppermost aquifer at the site is a surficial, unconfined aquifier, approximately 40-50 feet thick, composed of silty, fine to medium sand with mud lenses.

Method Description: The Summers model was developed to estimate the point at which contaminant concentrations in the soil will produce ground water contaminant concentrations above acceptable levels. The resultant soil concentrations can then be used as guidelines in estimating boundaries or extent of soil contamination and specifying soil cleanup goals for remediation.

The model assumes that a percentage of rainfall at the site will infiltrate the surface and desorb contaminants from the soil based on equilibrium soil:water partitioning. It is further assumed that this contaminated infiltration will mix completely with the ground water below the site, resulting in an equilibrium ground water concentration with all contaminants in the final mixture from the infiltration.

This model begins by estimating the concentration of the contaminant infiltration that would result in ground water concentrations at or below target levels. For this model the mixing rate of infiltration and ground water is estimated. The mixing of uncontaminated ground water with contaminated infiltration and the resultant concentrations in ground water can be calculated using the following equation:

$$C_{gw} = \frac{(Q_pC_p) \quad (Q_AC_A)}{Q_p + Q_A} \qquad (1)$$

where:

C_{gw} = contaminant concentration in the ground water (ug/l)

Q_p = $VD_z \bullet A_p$
= volumetric flow rate of infiltration (soil pore water) into the aquifer (ft^3/day)

VD_z = $Vs \bullet \varepsilon$
= Darcy velocity in the downward direction

V_s = ground water seepage velocity

ε = void fraction = ground water volume/volume of solid

A_p = horizontal area of pond or spill

C_p = concentrations of pollutant in the infiltration at the unsaturated-saturated zone interface

Q_A = VDhw
= volumetric flow rate of ground water (ft^3/day)

V_D = Darcy velocity in aquifer

h = thickness of aquifer

w = surface pond for spill width perpendicular to flow direction in aquifer

C_A = initial or background concentration of pollutant in aquifer.

The maximum allowable contaminant concentration in the infiltration (leachate) that would not result in a ground water concentration exceeding a water quality goal, such as an MCL, can be determined by using this water quality goal for C_{gw} in the previous equation and solving for the infiltration contaminant concentration:

$$C_p = \frac{C_{gw}(Q_p + Q_A) - Q_AC_A}{Q_p} \qquad (2)$$

Once the maximum allowable contaminant concentration in the leachate has been determined, the contaminant concentration in the soil can be calculated. This is the soil cleanup level which needs to be attained in order to be protective of the ground water and can be derived from the following soil:water partitioning equation:

$$C_s = (K_d)(C_p) \tag{3}$$

where:

C_s = soil concentration (ug/kg)

C_p = concentrations in the infiltration (ug/l)

K_d = an equilibrium partition coefficient (ml/g).

The use of K_d is based on the assumption that equilibrium conditions are maintained between the distribution of pollutant in solution and on the solid phase. Because equilibrium is more closely approached in slow moving soil pore water and ground water than in rapidly flowing surface water systems, it is feasible to apply K_d to soil pore water and ground water systems. Several methods to determine K_d values are described in Appendix D.

Data Requirements:

- Volumetric flow rate of infiltration (soil pore water) into the aquifer (ft^3/day)
- Darcy velocity in aquifer
- Ground water seepage velocity
- Void fraction (ground water volume/volume of solid)
- Horizontal area of pond or spill
- Volumetric flow rate of ground water (ft^3/day)
- Thickness of aquifer
- Initial or background concentration of pollutant in aquifer
- Concentration of contaminants in the infiltration (ug/l)

Site-Specific Cleanup Goals: Using the calculations as described below, these preliminary soil cleanup goals were established:

- Benzo(a)anthracene (0.140 mg/kg)
- Benzo(b and/or K)fluoranthene (0.170 mg/kg)
- PCB-Aroclor 1254 (1.050 mg/kg)
- Chromium (3.7 mg/kg)
- Lead (166.5 mg/kg)
- 1,1-Dichloroethane (0.00278 ug/kg).

Site-Specific Method Application: The Summers model, described earlier, was used at this site to determine the soil contaminant concentration level that would prohibit future leachate from exceeding target ground water concentrations. Using the following relationship, the target ground water cleanup concentrations and the mixing rate were used to back calculate contaminant concentrations in the leachate. This model is a derivation of the original equation (Summers, et al; 1980):

$$C_{gw} = \frac{(Q_p)(C_p)}{Q_p + Q_{gw}}$$

where: C_{gw} = contaminant concentration in ground water (µg/l)
Q_p = volumetric flow rate of infiltration (soil pore water) into ground water (ft^3/day)
Q_{gw} = volumetric flow rate of ground water (ft^3/day)
C_p = contaminant concentrations in the infiltration.

For this application, the volumetric flow rate of infiltration (Q_p) is measured as the total rainfall from the site minus the potential evapotranspiration. The contaminant concentrations in the ground water are then related back to soil concentrations using the soil:water equilibrium relationship as discussed in the model description.

The partition coefficient (K_d) that was used in the model at this site was derived from the following equation:

$$K_d = (K_{oc})(F_{oc})$$

where: K_{oc} = organic carbon partition coefficient
F_{oc} = fraction of organic carbon in the soil.

No measurements were taken at the site, therefore the fraction of organic carbon in the soil was assumed to be 0.5 percent (typical for sandy soils).

These calculations yield soil cleanup levels which may prevent ground water from exceeding established protective criteria.

Site Name: **Pinette's Salvage Yard, ME**

Contaminants: PCB - Aroclor-1260
1,4-Dichlorobenzene
1,2,4-Trichlorobenzene
Chlorobenzene
Benzene
Chloromethane

Depth to Ground Water: Ranged from 0-6 feet

Data Requirements:

- Volumetric flow rate of recharge flowing downward through a unit area (ft^3/day)
- Volumetric flow rate of ground water in saturated zone in water column through unit width (ft^3/day)
- Concentration of contaminant in ground water recharge
- Hydraulic conductivity (ft/day)
- Hydraulic gradient (ft/ft)
- Concentration of contaminant adsorbed to the soil in the unsaturated zone (ug/kg)
- Concentration of contaminant in ground water in saturated zone (ug/l)
- Total organic carbon concentration (mg/mg)

Method: **Unnamed** - This method is a variation of the Summers Model. A separate critical soil concentration or soil cleanup level is derived for both saturated and unsaturated soils designed to prevent ground water from exceeding regulatory or health-based levels. These cleanup values are calculated based on ground water contamination, equilibrium partitioning and dilution.

Source: Pinette's Salvage Yard Feasibility Study, Appendix B, (Draft), 1989.

Case Study: **Pinette's Salvage Yard, ME**

Waste Description: The contamination at the site was found in ground water and soils. The contaminants of concern and their maximum concentrations were as follows:

PCB-Aroclor-1260	(92 ppb)
1,4-Dichlorobenzene	(5.1 ppm)
1,2,4-Trichlorobenzene	(510 ppm)
Chlorobenzene	(260 ppb)
Benzene	(18 ppb)
Chloromethane	(58 ppb)

Soil Type: There are four distinct soil units at the Pinette site: surficial soils (alluvium), a clay/silt confining unit, a sequence of glacial till/glacial outwash, and a bedrock unit.

Depth to Ground Water: Portions of the site consist of wetlands or "ground water breakout" areas. Two distinct aquifers under the site are separated by an intervening clay layer found 2 to 6 feet below the ground surface extending to depths of 12 to 16 feet. The clay unit acts as a aquitard in the shallow allivial aquifer, resulting in a saturated thickness ranging from 2 to 3 feet.

Method Description: This Unnamed method developed soil cleanup criteria using established ground water regulatory and health-based levels coupled with an equilibrium partitioning approach.

Soil cleanup levels are calculated for saturated and unsaturated soils assuming equilibrium between dissolved and adsorbed phases for each contaminant using the following relationship:

$$S_{sat} = (K_d)(C_{sat}) \qquad (1)$$

where:
S_{sat} = concentration of contaminant adsorbed to the soil in the saturated zone (ug/kg)
K_d = distribution coefficient
C_{sat} = concentration of contaminant in ground water in saturated zone

The K_d can be derived by several methods (Appendix D); however, in this case the K_d was calculated as follows:

$$K_d = (0.63)(F_{oc})(K_{ow}) \qquad (2)$$

where:
0.63 = adjustment factor
F_{oc} = total organic carbon concentration in soil (mg/mg)
K_{ow} = octanol-water partition coefficient

Next, the desired contaminant concentration for ground water is determined using established health-based criteria (i.e., MCLs, cancer risk values). The cleanup criteria may now be calculated using equation (1).

Subsequent calculations to derive unsaturated soil cleanup criteria include the assumption that dissolved contamination in the ground water recharge reaches equilibrium with the absorbed phase on unsaturated soils, and that such recharge is fully diluted into the entire water column upon reaching the water table. Thus, cleanup criteria for unsaturated soils are established using equation (1) and a dilution equation for calculating (C_{sat}) the contaminant concentration in the ground water in the saturated zone.

$$C_{sat} = (C_{unsat})(e)/(e+Q) \tag{3}$$

where: C_{unsat} = contaminant concentration of ground water in recharge (ug/l)
e = volumetric flow rate of recharge flowing downward through a unit area (ft^3/day)
Q = volumetric flow rate of ground water in the saturated zone throughout the unit (ft^3/day)

The equilibrium assumption;

$$S_{unsat} = (K_d)(C_{unsat}) \tag{4}$$

combined with equation (3) yields the following relationship. This equation is used to calculate the cleanup criteria for soils in the unsaturated zone.

$$S_{unsat} = (S_{sat})(e + Q)/e \tag{5}$$

where: S_{unsat} = concentration of contaminant adsorbed to the soil in the unsaturated zone (ug/kg)

and the ground water volumetric flow rate through the saturated zone (Q) is estimated from Darcy's Law:

$$Q = (K)(i)(A) \tag{6}$$

where: K = hydraulic conductivity (ft/day)
i = hydraulic gradient (ft/ft)
A = area of flow (unit width x saturated thickness of aquifer) (ft^2)

Data Requirements/Processes Addressed:

- Concentration of contaminant adsorbed to the soil in the saturated zone (ug/kg)
- Concentration of contaminant in ground water in saturated zone (ug/l)
- Total organic carbon concentration in soil (mg/mg)
- Octanol-water partition coefficient
- Concentration of contaminant in ground water recharge
- Volumetric flow rate of recharge flowing downward through unit area (ft^3/day)
- Volumetric flow rate of ground water in the saturated zone throughout the water column (ft^3/day)

Site-Specific Cleanup Goals: Using the calculations described below and the values listed in Exhibit 2, the following soil cleanup goals were established:

	Saturated Soils	Unsaturated Soils
PCB-Aroclor-1260	(8,700 ug/kg)	(5,394,000 ug/kg)
1,4-Dichlorobenzene	(42 ug/kg)	(26,000 ug/kg)
1,2,4-Trichlorobenzene	(7,800 ug/kg)	(4,836,000 ug/kg)
Chlorobenzene	(20 ug/kg)	(12,000 ug/kg)
Benzene	(0.42 ug/kg)	(260 ug/kg)
Chloromethane	(0.05 ug/kg)	(30 ug/kg)

Site-Specific Method Application: At Pinette's Salvage Yard Site the F_{oc} was estimated to be 0.1 percent. For Aroclor-1260, K_{ow} is given in Walton (1984) as 1.38×10^7. Using equation (2), the distribution coefficient (K_d) was estimated as follows:

$$\begin{aligned} K_d &= (0.63)(0.001)(1.38 \times 10^7) \\ &= 8.69 \times 10^3 \end{aligned}$$

The ground water cleanup criteria (Contract Laboratory Required Quantitation Limits) used for Aroclor-1260 was 1.0 ug/l. Using equation (1) the corresponding soil cleanup criteria in the saturated zone was determined:

$$\begin{aligned} S_{sat} &= (8.69 \times 10^3)(1.0) \\ &= 8{,}700 \text{ ug/kg} \end{aligned}$$

Exhibit 2
SOIL CLEANUP CRITERIA FOR PINETTE'S SALVAGE YARD

Compound	Ground Water Cleanup Criteria (ug/1)	Source	Octanol-Water Partition(K_{ow}) Coefficient	Distribution Coefficient(K_d) (ml/g)	Critical Soil Concentration(s) (ug/kg)
Saturated Conditions:					
Aroclor-1260	1	CRQL	1.38×10^7	8.69×10^3	8,700
1,4-Dichlorobenzene	27	MEG	2.45×10^3	1.54×10^0	42
1,2,4-Trichlorobenzene	680	Risk-Based Hazard Index	1.82×10^4	1.15×10^1	7,800
Chlorobenzene	47	MEG	6.92×10^2	4.36×10^{-1}	20
Benzene	5	MEG	1.35×10^2	8.50×10^{-2}	0.42
Chloromethane	10	CRQL	8.13×10^2	5.72×10^{-3}	0.05
Unsaturated Conditions:					
Aroclor-1260					5,394,000
1,4-Dichlorobenzene					26,000
1,2,4-Trichlorobenzene					4,836,000
Chlorobenzene					12,000
Benzene					260
Chloromethane					30

Notes:

1. Ground water cleanup criteria derived from health-based criteria, Maine Maximum Exposure Guidelines (MEGs) and Contract Laboratory Program Contract Required Quantitation Limits (CRQLs).
2. Octanol-water partition coefficients (K_{ow}) are based on Walton, 1984.
3. The distribution coefficient (K_d) is a function of the octanol-water partition coefficient, and the soil total organic carbon concentration (F_{oc}) as follows: $K_d = 0.63 (F_{oc})(K_{ow})$
   A regional subsurface soil total organic carbon value of 0.10 percent (0.001) was used based on Soil Conservation Service data.
4. For saturated conditions, $S = K_dC$
5. For unsaturated conditions, $S = 620\ K_dC$
6. Low-level soil practical quantification limits (PQLs) are as follows:
   Benzene 2 ug/kg; 1,4-Dichlorobenzene 3 ug/kg (Analytical Method 8020); Chlorobenzene 0.8 ug/kg (Analytical Method 8010)
7. Area of flow is assumed to be 2.5 ft^2
8. Hydraulic gradient is estimated to be 0.025 (ft/ft

The soil cleanup criteria in the unsaturated zone were calculated using equation (5). In order to use equation (5), however, a value for (Q), the volumetric flow rate through the saturated zone, must be calculated using equation (6).

$$Q = (45 \text{ ft/day})(0.025)(2.5 \text{ ft}^2)$$
$$= 2.25 \text{ ft}^3\text{/day}$$

Assuming an annual recharge rate of 20 in/year and a unit area of 1 ft^2, a value for the volumetric flow rate of recharge flowing downward through a unit area (e) was estimated as 4.6×10^{-3} ft^3/day. Referring back to equation (5) (e + Q)/e is equal to 620. Therefore, the critical unsaturated soil concentrations will be 620 times the critical saturated soil concentrations for any individual contaminant. For Aroclor-1260, this value was calculated as follows:

$$S_{sat} = (8{,}700 \text{ ug/kg})(620)$$
$$= 5{,}394{,}000 \text{ ug/kg.}$$

Site Name: **Pristine Inc., OH**

Contaminants:		
	Aldrin	Dieldrin
	Benzene	PAHs
	Chloroform	2,3,7,8-TCDD
	DDT	Tetrachloroethene
	1,1-Dichloroethene	Trichloroethane
	1,2-Dichloroethene	

Depth to Ground Water: Ranges from 0-46 feet

Data Requirements:

- Volumetric flow rate of infiltration (soil pore water) into aquifer
- Darcy velocity in aquifer
- Ground water seepage velocity
- Void fraction (ground water volume/volume of solid)
- Horizontal area of contamination
- Volumetric flow rate of ground water (ft^3/day)
- Thickness of aquifer
- Background contaminant concentration in aquifer (ug/l)
- Contaminant concentrations in the infiltration (ug/l)

Method: **Summers Model** - Refer to Geiger Case Study for full description.

Source: Summers, K.S., Gherini and C. Chen, Tetra Tech, Inc., Methodology to Evaluate the Potential for Groundwater Contamination from Geothermal Fluid Release, EPA-600/7-80-117, 1980, as modified by EPA Region IV.

Case Study: Pristine Inc., OH

Waste Description: As part of the Public Health Evaluation, 11 compounds were identified as "chemicals of concern" based on frequency, concentration and potential threat. These compounds were:

Aldrin
Benzene
Chloroform
DDT
1,1-Dichloroethene
1,2-Dichloroethene
Dieldrin
PAHs
2,3,7,8-TCDD (dioxin)
Trichloroethane
Tetrachloroethene

Soils are contaminated to a depth of approximately 14 feet.

Soil Type: The site geology consists of five distinct soil units: fill, upper lake sediment, glacial till, lower lake sediment, and lower outwash. The outwash and other glacially derived sediments are about 180 feet thick underlain by 2 aquifers.

Depth to Ground Water: The top of the upper aquifer lies within the upper lake sediments, which is estimated to be approximately 0 - 46 feet. The precise depth of the ground water table was not specified in the Record of Decision (ROD). Because there are wetlands adjacent to the site, however, the water table is expected to be near the surface.

Method Description: (Summers Model - See Geiger Case Study for full description)

Data Requirements/Processes Addressed:

- Volumetric flow rate of infiltration (soil pore water) into the aquifer (ft^3/day)
- Darcy velocity in aquifer
- Ground water seepage velocity
- Void fraction (ground water volume/volume of solid)
- Horizontal area of pond or spill
- Volumetric flow rate of ground water (ft^3/day)
- Thickness of aquifer
- Surface pond for spill width perpendicular to flow direction in aquifer
- Initial or background concentration of pollutant in aquifer
- Concentration of contaminants in the infiltration (ug/l)

Site-Specific Cleanup Goals: Using the Summers calculations described in Geiger Case Study, the following cleanup criteria were derived:

- Benzene (116 mg/kg)
- 1,2-Dichlorobenzene (19 mg/kg)
- Trichlorobenzene (175 mg/kg)

Site-Specific Method Application: The preliminary performance goals for soil were designed to prevent cancer risks from exceeding 10^{-6} as a result of exposure to the chemicals of concern. After calculating soil cleanup levels based on dermal exposure and ingestion of soil, the "Summers" model was used to verify that soil cleanup concentration levels, based on the above exposure pathways, were also protective of ground water. Of the 11 contaminants of concern identified at the site, model calculations indicated that the concentrations of 3 of the contaminants would exceed MCLs.

The mixing of ground water, infiltrating water and the resultant contaminant concentrations in ground water were related as follows:

$$C_{gw} = \frac{(Q_p)(C_p)}{Q_p + Q_{gw}} \qquad (1)$$

where:
C_{gw} = contaminant concentration in the ground water (ug/l)
Q_p = volumetric flow rate of infiltration (soil pore water) into the ground water (ft^3/day)
C_p = contaminant concentration in the infiltration
Q_{gw} = volumetric flow rate of ground water (ft^3/day)

The volumetric flow rate of infiltration (Q_p) was derived based on the total rainfall from the site, 40 inches, and attributed 15 percent to ground water recharge, or approximately 6 in/year.

This quantity is assumed to have fallen over the entire site on 120,000 square feet corresponding to a Q_p value of 164 ft^3/day. The volumetric flow rate of ground water (Q_{gw}) is estimated as the average linear ground water velocity times the area of the aquifer perpendicular to the ground water flow across the contaminated area of the site or 8,900 ft^3/day.

This value was derived using the following equation:

$$Q_{gw} = (k)(i)(l)(d) \tag{2}$$

where:
- k = hydraulic conductivity (139 ft/day)
- i = hydraulic gradient (0.00245 ft/ft)
- l = length of the site perpendicular to flow (600 ft)
- d = depth of aquifer or mixing zone (43.4 ft)

The hydraulic conductivity was based on regional pumping tests. The depth of the mixing zone was taken to be one-third the depth that the area municipal wells were screened.

The concentration in the infiltrating ground water (C_p) was predicted using the following relationship:

$$C_s = (K_d)(C_p) \tag{3}$$

where:
- C_s = measured soil concentration (ug/kg)
- K_d = soil:water equilibrium partition coefficient (liter/kg)
- C_p = concentration in infiltration (ug/liter)

In this case, the partition coefficient (K_d) was derived by multiplying the organic carbon water partition coefficient (K_{oc}) by the fraction of organic carbon (F_{oc}) as follows:

$$K_d = (K_{oc})(F_{oc}) \tag{4}$$

The fraction of organic carbon was assumed to be 0.5 percent based on descriptions of soil found onsite.

A back calculation was subsequently performed to determine the appropriate soil performance level required to prevent the ground water contaminant levels from exceeding MCLs. These levels were selected as the target cleanup level for the contaminants.

SPPPLV

Site Name: Chemtronics, NC

Contaminants:
Toluene
Lead
RDX
Benzophenone
Chromium
TNT
Picric acid
2-Chlorobenzolmalonitrile

Depth to Ground Water: Ranges from 0-40 feet

Data Requirements:

- Measured concentrations of contaminants in soil and other media of critical pathways
- Acceptable daily intakes for each contaminant
- Distance from site receptor
- Rate of offsite migration
- Rate of contaminant degradation

Method: **SPPPLV** - This method was developed by the U.S. Army. It requires the identification and measurement of pollutants present, pathways of exposure, and the determination or estimation of an acceptable daily dose of each contaminant to a receptor.

Source: U.S. Army, "Single Pathway Preliminary Pollutant Limit Values and Preliminary Pollutant Limit Values (SPPPLV and PPLV)," In Inventory of Cleanup Criteria and Methods to Select Criteria, (Unpublished Report), G.M. Richardson, Environment Canada, 1987.

Case Study: Chemtronics, NC

Waste Description: Every environmental medium was found to be contaminated at this site, including ground water, surface water, sediments, air and soil. The indicator compounds selected at the site included nine volatile organic compounds, three explosive compounds, three chemical warfare agents and two metals. The concentrations of contaminants found varied with each area. Some of the higher levels founds in the soil were:

- Toluene (21,000 mg/kg)
- RDX (290 mg/kg)
- TNT (280 mg/kg)
- 2-Chlorobenzalmalonitrile (CS) (3,100 mg/kg)
- Lead (35 mg/kg)
- Chromium (97 mg/kg)
- Picric acid (22 mg/kg)
- Benzophenone (9.3 mg/kg)

Soil Type: The soil types were not provided in the Record of Decision (ROD).

Depth to Ground Water: Ground water recharge in the onsite area is derived primarily from local precipitation. Generally, the depth of the water table depends on the topography and rock weathering at the site. The ground water table varies from the ground surface in the valleys (streams) to more than 40 feet below the ground surface in sharply rising slopes. The ground water underlying the site has been classified as IIb, using USEPA Ground-Water Protection Guidelines.

Method Description: The method applied at Chemtronics is a mathematical model developed by the U.S. Army to determine site-specific cleanup levels. It requires the identification and measurement of pollutants present, pathways of exposure, and the determination or estimation of an acceptable daily dose (D_t) of each contaminant to a receptor.

Single pathway preliminary pollutant limit values (SPPPLV) for all pathways and contaminants are calculated from measured levels of contaminants at a particular site. The acceptable daily intake for each contaminant, as well as site-specific factors such as distance to receptor, rate of offsite migration, and rates of dilution and degradation are used in the model. Assuming that contaminants are in equilibrium along all exposure pathways from source to receptor, partition coefficients can be used to determine levels of contaminants in different media along the exposure pathways. Critical pathways are selected for each contaminant, and a preliminary pollutant limit value (PPLV) is then derived for each medium by normalization of the SPPPLV using the following equation:

$$\mathrm{PPLV} = \left(\sum_{1}^{n} \frac{1}{(\mathrm{SPPPLV})_i}\right)^{-1}$$

In order to establish PPLVs the best available toxicological information is used to estimate an acceptable daily dose (D_t) for human exposure to each compound (Exhibit 3). A PPLV is derived from consideration of the D_t along with the probable exposure level.

The soil contaminant concentration is related to the ground water concentration through the following relationships:

$$K_{sw} = \frac{C_w}{C_s} \tag{1}$$

where: C_s = acceptable contaminant concentration in soil
C_w = acceptable contaminant concentration in water
K_{sw} = partition coefficient (soil/water)

From the estimated D_t, an estimated ground water limit value is expressed as:

$$\text{Ground Water PPLV} = \frac{D_t \times \text{body weight}}{\text{daily water intake}} \tag{2}$$

The PPLV for ground water, which has been calculated using an acceptable daily intake, can then be used to derive an appropriate site-specific soil cleanup level.

This model is applicable to all sites, receptors and contaminants, and can be applied to multimedia and multi-contaminant exposures.

Data Requirements:

- Measured concentrations of contaminants in soil and other media of critical pathways
- Acceptable daily intake for each contaminant
- Various site-specific parameters, including distance from site to receptor, rate of offsite migration, and rates of dilution and degradation of contaminants.

Site-Specific Cleanup Goals: The PPLVs established for explosives and chemical agents at the site were determined for both soil and drinking water based on predicted exposure pathways. The contaminant levels determined to be safe to human health according to the PPLV method were as follows:

TNT (305 mg/kg)
Picric acid (38,000 mg/kg)
CS (43.4 mg/kg)
RDX (95 mg/kg)
3-Quinuclidinol (25.7 mg/kg)
Benzophenone (15 mg/kg)

Exhibit 3
ACCEPTABLE EXPOSURE LEVELS

Information sources from which to derive values of acceptable daily doses (D_T) of toxic pollutants for humans (order of priority)

Input Information	Calculation Required	Reference
Existing Standards		
Acceptable daily intake (ADI)	None	WHO (1962)
Maximum concentration level (MCL) in drinking water	Adjust for water consumption level	EPA (1975)
Threshold limit value (TLV) for occupational exposures	Use factors for breathing rate, exposure time, safety factor of 10^{-2}	ACGIH (1980), Cleland, et al, (1987)
FDA guidelines for concentrations in foods	Use factors for consumptions of particular foods	FDA
Experimental Results in Laboratory Animal Studies		
Lifetime no-effect level (NELL)	Use safety factor of 10^{-2}	Vettorazzi (1976)
Ninety-day no-effect level (NEL_{90})	Use safety factor of 10^{-3}	Vettorazzi (1976)
Acute toxicity (LD_{50})	Use safety factor of 1.155×10^{-5}	Rosenblatt (1982)

Site-Specific Method Application: The presence of residual contamination from the three chemical agents and three explosives onsite presented a special problem with respect to establishing target cleanup levels. Since these chemicals lack or have minimal data concerning health standards or toxicological information, the preliminary pollutant limit value method was selected to develop acceptable response action levels. The application of the PPLV method was modified at the Chemtronics site. At this site the acceptable soil concentrations and acceptable water concentrations were determined separately and not related by the K_{sw}.

The PPLVs for 3-Quinuclidinol, as one of the target compounds, were calculated by first establishing a D_t level. Using the LD_{50} value of 179 mg/kg (Exhibit 4), and a safety factor of 1.5×10^{-6} according to the Layton method (Layton et al., 1987), a D_t of 2.7×10^{-4} mg/kg/day was derived. Using this D_t value in equation (2) a PPLV for ground water is calculated as follows:

$$\text{Ground Water PPLV} = \frac{D_t \times \text{body weight}}{\text{daily water intake}}$$

$$= \frac{2.7 \times 10^{-4}\text{mg/kg/day} \times 70 \text{ kg}}{2 \text{ liters}}$$

$$= 0.009 \text{ mg/l}$$

For soil, two exposure pathways, ingestion and absorption, were considered. The action level for soil concentrations that provide reasonable protection for soil ingestion by a 15 kg child is then calculated by:

$$\text{Soil ingestion (SPPPLV)} = \frac{D_t \times \text{body weight}}{\text{amount of soil ingested}}$$

$$= \frac{2.7 \times 10^{-4}\text{mg/kg/day} \times 15 \text{ kg}}{0.0001 \text{ kg soil}}$$

$$= 40.5 \text{ mg/kg}$$

The specific pathway preliminary pollutant limit value for skin absorption is based on a 10kg child absorbing only 38.6×10^{-6} kg of soil in a day. This is calculated as follows:

$$\text{Skin Absorption (SPPPLV) for soil} = \frac{D_t \times \text{child weight}}{\text{kg soil/day}}$$

$$= 70 \text{ mg/kg}$$

Exhibit 4
PARAMETER VALUES FOR CHRONIC HUMAN EXPOSURE USED AT CHEMTRONICS

Parameters	Value
Adult body weight	70 kg
Adult water intake	2 l/day
Adult breathing rate	18.5 m^3/24 hr
Adult dust inhalation (rural)	0.06 mg/m^3/day
Child body weight (1 to 6 yrs)	15 kg
Soil from which contaminants would be removed through skin absorption by child	0.0386 g/day
Soil ingestion by 15 kg child	0.1 g/day
De minimis risk for small populations (less than 10 million)	10^{-4}
Temperature	25°C

The PPLV for soil when considering ingestion and skin absorption is then calculated by:

$$\text{Soil PPLV} = \frac{1}{\frac{1}{40.5} + \frac{1}{70}}$$

$$= 25.7 \text{ mg/kg}$$

ANALYTICAL METHODS

Site Name: **Hollingsworth, FL**

Contaminants: Copper
Nickel
Lead

Depth to Ground Water: At or near surface.

Data Requirements:

- Advisory levels of contaminants (e.g., PPCLs)

Method: **Exposure Assessment Using Leachate Tests** - This methodology employs leachate extraction tests on contaminated soils and applies them to existing health advisory levels.

Source: Contaminated Soils Workgroup Preliminary Findings and Recommendations, (Draft), Exposure Assessment Using Leachate Tests Methodology.

Case Study: **Hollingsworth, FL**

Waste Description: The onsite soil contained contaminants including copper (21.7 ppm), nickel (0.3 ppm), and lead (0.2 ppm).

Soil Type: The first 60 to 70 feet of soils are primarily composed of fine to medium grained sands. This zone is underlain by a transition zone of cemented shell and sandstone, and finally by limestone, which forms the major water transporting zone of the aquifer.

Depth to Ground Water: The Biscayne Aquifer, a highly permeable, wedge-shaped, unconfined shallow aquifer, underlies the site and is the primary source of drinking water for 3 million residents. The top of the aquifer is near the natural ground surface in the area of the site.

Method Description: The methodology employed at this site applied various leachate extraction tests to contaminated soils to determine estimated contaminant concentration levels in leachate. Acceptable leachate levels were related to site conditions and advisory levels (e.g., primary pollutant concentration levels, or PPCLs). Extraction procedures used include the EP Toxicity Test for substances with drinking water standards, as well as the Toxicity Characteristic Leaching Procedure (TCLP). All leachate tests were used in conjunction with a modified version of Trescott and Laren's (USGS) Finite Difference three-dimensional ground water fate and transport model in order to determine the "reasonable worst case" protection levels in soil.

The advantage in using this methodology is its ability to relate concentration and mobility of the hazardous substance to site-specific conditions. For additional information on the use of leachate tests for determining soil cleanup levels and a description of several of the tests available, refer to Appendix C.

Data Requirements: The only information required to apply this method is the advisory levels of contaminants, such as PPCLs, and leachate analysis of soil samples from representative locations at the site.

Site-Specific Cleanup Goals: The cleanup goals for soil were established based on drinking water standards. The contaminant concentration in the leachate from the soils were not to exceed a level 10 times the appropriate State water quality criteria. Hence, the cleanup criteria were as follows: copper (10 ppm), nickel (1.0 ppm), lead (0.5 ppm), and total VOCs (1.0 ppm).

Site-Specific Method Application: The attainment of cleanup goals at this site for metal-contaminated soil were determined based on the concentration of the metals in the soil leachate (as determined by an EP Toxicity test). The cleanup goals for soil were set at the level at which the leachate from these soils did not exceed 10 times the appropriate State water quality criteria, following negotiations between EPA and the FDER. A factor of 10 has been designated by Region 4 as a conservative baseline in estimating the level of the dilution of leachate as it reaches the ground water. The soil then was excavated to these cleanup goals using the results obtained from the EP Toxicity test to indicate when the selected cleanup levels had been achieved.

GENERIC METHODS

Site Name: **Woodbury Chemical, CO**

Contaminants: Alpha-BAC
Iron
Manganese
Acetone

Ground Water Depth: 20 to 27 feet

Data Requirements:

- Background levels of contaminants in on- or offsite soils

Method: **Background Levels** - This method requires that a background soil contaminant concentration be established for use as a guide in determining soil cleanup levels.

Source: Contaminated Soils Workgroup, Preliminary Findings and Recommendations, (Draft), Background Levels Methodology.

Case Study: Woodbury Chemical, CO

Waste Description: An estimate of 5,470 cubic yards of onsite soil and sediments, as well as offsite sediments are contaminated with three general types of contaminants including pesticides, metals and other organic compounds. The high concentrations are found in "hot spots" where rubble had been deposited. Pesticide-contaminated soils were found at varying depths at the site, indicating that some downward migration has occurred, but they do not appear to have dissolved into ground water in large amounts. The pesticide concentrations across the site ranged from below detection limit to 151,515 ppm for alpha-BHC. Iron and manganese were found at concentrations as high as 32,600 ppm and 1,200 ppm respectively, and acetone was detected at 15 ppm.

Soil Type: Bedrock lies at a depth of about 30 feet below alluvial deposits.

Depth to Ground Water: The ground water hydrology of the area is characterized by unconfined aquifer conditions in the alluvium and semi-confined aquifer conditions in the underlying bedrock. The water table is located 20 to 27 feet below the ground surface.

Method Description: The use of the background contamination method requires that a background contaminant concentration level at the site or offsite must be established as the target cleanup level for onsite soils. This ensures the site will be cleaned up to the level prevailing in the area.

The primary advantage to using this methodology is protection of public health and the environment by returning contaminant levels to the original background level. In addition, once the background level is established, attainment of this cleanup level can be determined through total contaminant concentration analysis of the soil. These analytical results can be obtained relatively quickly and with less effort compared to using a model or other methodology.

Data Requirements: Background levels of contaminants in on- or offsite soils.

Site-Specific Cleanup Goals: Due to the carcinogenic properties of aldrin and dieldrin, a risk-specific dose cleanup level of 1.0 ppm and 0.5 ppm, respectively, was set for these pesticides. The limit value selected for the remaining pesticides is that total soil concentration not exceed 3.0 ppm, as determined using background concentrations and the methodology detailed in the following section.

Site-Specific Method Application: The following criteria were used to determine the appropriate residual pesticide concentrations or proposed pollutant limit value (PPLV) that should be set for cleanup of this site:

- "Typical" pesticide residual soil concentrations in urban areas
- Comparison to RCRA standards
- Potential cancer risk.

The contaminant pesticides at the site are the types that were available for use in the urban environment from the 1960s to the mid-1970s for pest control. Therefore, typical pesticide residual soil concentrations were calculated based on summary data for the period 1969-1976 from the National Soils Monitoring Program. Urban soils data for the concentrations of chlordane, heptachlor, heptachlorepoxide, dieldrin, endrin, toxaphene, and total DDT from five cities were selected to represent a western or Great Plains urban environment. A value of 3.0 ppm total pesticides was selected as a appropriate cleanup level because, based on the data received, it is an approximate average urban total pesticide soils concentration.

In order to ensure that the 3.0 ppm cleanup value was a legitimate and acceptable value, it was first compared to the established RCRA concentration of 0.005 mg/l for toxaphene in ground water directly outside of a site boundary (40 CFR 264.94(a)(1)). The 3.0 ppm value was determined, using a volumetric calculation method to represent 5.0 kg of total pesticide remaining on the 2.2-acre site. The potential delivery of pesticides to the alluvial aquifer (at a depth of 20 feet) was calculated based on the following:

- Relative concentrations of pesticides in the soil - toxaphene found to comprise approximately 90 percent of the total pesticides, chlordane approximately 3 percent, and all others 1 percent or less.
- Solubility of pesticides - values taken from published data and selected and used to represent the most realistic conditions.
- Pesticides half-lives - values from current literature obtained for the half-life for each pesticide. Values integrated with the calculated travel time to estimate degradation.
- Recharge to site - consisted of a water balance equation that considered net precipitation and permeability of the soil. Modified Darcian equations used to estimate recharge.

- Dilution by the alluvial aquifer - considered in the delivery calculations and included permeability, transmissivity and storativity calculations.

Empirically-derived adsorption equations were then used to calculate concentrations in the alluvial aquifer at the site boundary, based on an urban background soil concentration of 3.0 ppm. The derived water concentration was 0.000035 mg/l, which is greater than two orders of magnitude less than the RCRA concentration limits, so the cleanup level of 3.0 ppm was considered to be protective.

Site Name: Distler Farm, KY

Contaminants: Arsenic
Bis(2-ethylhexyl) phthalate
Chromium
Di-n-butyl phthalate
Lead
Isophorone
Benzene
Toluene
Trichloroethylene
Tetrachloroethylene
Naphthalene

Depth to Ground Water: 5 to 10 feet

Data Requirements:

- Background levels of contaminants in on- and offsite soil.

Method: Background Levels - This method requires the determination of background soil contaminant concentration to be used as a baseline for the establishment of soil cleanup levels.

Source: Contaminated Soils, Workgroup, Preliminary Findings and Recommendations, (Draft), Background Levels Methodology.

Case Study: Distler Farm, KY

Waste Description: Contaminants of concern found in soil samples within the area of contamination include arsenic, chromium, lead, benzene, toluene, trichloroethylene, tetrachloroethyelene, naphthalene, bis(2-ethylhexyl) phthalate, di-n-butyl phthalate, and isophorone. Test data indicated that the contaminants have been released, distributed, or have migrated to soil depths ranging from six inches to four feet.

Soil Type: The upper soil layers are primarily clayey and silty in nature and range from 5 to 20 feet. The average depth is approximately 15 feet.

Depth to Ground Water: The onsite water table fluctuates due to seasonal flooding, the average depth to ground water is approximately 5-10 feet.

Method Description: This method requires that an average background contaminant level in offsite soils be determined in order to establish the target cleanup level for onsite soils. This method ensures that the site will be cleaned up to the same level as the prevailing levels in the surrounding area.

Once the background level is established, attainment of this cleanup level can be determined through laboratory analysis of the soil. These analytical results can be obtained relatively quickly and with less effort in contrast to modeling techniques.

Data Requirements: Background concentrations of contaminants of concern in uncontaminated or offsite soils.

Site-Specific Cleanup Goals: With the exception of arsenic, which was detected at background levels of 20 ppm in area soils, soil background levels for contaminants of concern were equal to the method detection limits (2.5 to 100 ppm). These contaminants were not detected in uncontaminated soils in the area.

Site-Specific Method Application: All contaminated soils were to be excavated to background levels and disposed of in an offsite permitted hazardous waste landfill. For estimating purposes, the depth of excavation that would be required to reach background level was assumed to be 11 feet. During excavation, periodic sampling was performed to ensure that when "background" levels were obtained, excavation efforts were stopped.

Site Name: **Hocomonco Pond, MA**

Contaminants:

Benzo(a)pyrene
Naphthalene
Phenanthrene
Anthracene
2-Methyl naphthalene
Flouranthene
Benzo(a)anthracene
Chrysene
Dibenzofuran
Pyrene
Flourene
Arsenic
Chromium
Lead

Depth to Ground Water: Not provided in documentation.

Data Requirements:

- Visible identification of and distinction between contaminated and noncontaminanted soils

Method: **Visible Contamination** - The soils are removed to a depth at which they are no longer visibly contaminated.

Source: Contaminated Soils Workgroup, Preliminary Findings and Recommendations, (Draft), Background Levels Methodology.

Case Study: Hocomonco Pond, MA

Waste Description: Site contaminants were found in the air, ground water, surface water, sediments, and soil. Specific soil samples taken from the Kettle Pond area and several other isolated areas contained the following contaminants:

Benzo(a)pyrene	(ND - 11 ppm)
Naphthalene	(0.007 - 0.141 ppm)
Phenanthrene	(0.002 - 0.129 ppm)
Anthracene	(0.003 - 0.050 ppm)
2-Methyl naphthalene	(0.007 - 0.012 ppm)
Fluoranthene	(0.006 - 0.483 ppm)
Benzo(a)anthracene	(0.004 - 0.097 ppm)
Chrysene	(0.001 - 1.0 ppm)
Dibenzofuran	(ND - 0.017 ppm)
Pyrene	(ND - 0.287 ppm)
Fluorene	(ND - 0.207 ppm)
Arsenic	(1 - 21 ppm)
Chromium	(2 - 52 ppm)
Lead	(1 - 21 ppm).

The depth of soil contamination in the Kettle Pond area extends from the surface to a depth of 26 feet (maximum depth sampled and analyzed).

Soil Type: The typical stratigraphic sequence of surficial deposits from base to top of the site consists of 0-4 feet of dense lodgement, till under 0-100 feet of delta forset beds, followed by 0-30 feet of delta topset beds.

Depth to Ground Water: The site was divided into four primary areas. The depth to ground water varied throughout these areas. It was determined, however, that the excavation of soils was necessary at only two of the areas, Kettle Pond and Hocomonco Pond. The depth to ground water was not provided specifically for either of these areas.

Method Description: The method used at this site targets visibly contaminated soils for cleanup. Soils are removed to a depth at which they are no longer visibly contaminated. This methodology assumes that soils that are not visibly contaminated will not significantly contaminate ground water or present a threat through dermal contact. It may be appropriate, if data indicate, that contaminants have not migrated beyond the layer where visible contamination exists.

Data Requirements: Visible identification of and distinction between contaminated and noncontaminated soils.

Site-Specific Cleanup Goals: The primary limits of soil excavation for this site have been chosen based on visual contamination criteria.

Site-Specific Method Application: The remedial action recommended for the Kettle Pond area consisted of excavation of contaminated soil with disposal in an onsite RCRA landfill. The extent of soil excavation (i.e., the target cleanup level) was based primarily on visible contamination criteria but included post-excavation boring and monitoring well sampling to ensure all highly contaminated soils were removed. The sampling and analyses was used to identify an area where the visible contamination ceased and a sharp decrease in concentrations occurred. This depth was targeted as the actual depth of excavation. Subsequent ground water monitoring was planned to ensure that contaminated soils were excavated to the depth necessary to mitigate potential ground water contamination. The range of visible contamination observed in the Kettle Pond area was 11 to 17 feet; however, the extent of excavation beyond visible contamination and highly contaminated soils, based on a marked reduction in contaminant concentration, was expected to be approximately 2 to 3 feet beyond this in order to be protective.

Site Name: **Pacific Place, British Columbia, Canada**

Contaminants: Exhibit 5 provides a detailed list.

Depth to Ground Water: Not provided in documentation.

Data Requirements:

- Types and levels of contaminants found onsite
- The intended land use for the site after remediation efforts are completed

Method: **Investigation and Remediation Standards** - This methodology uses established criteria and projected future land uses of a site to establish soil cleanup criteria.

Source: British Columbia Standards for Managing Contamination at the Pacific Place Site, Ministry of Environment, Waste Management Program, Victoria B.C., April 5, 1989.

Exhibit 5
INVESTIGATION AND REMEDIATION STANDARDS FOR PACIFIC PLACE

Soil (mg/kg) or (ppm) of dry matter

	A	B	C
HEAVY METALS			
Arsenic	5	30	50
Barium	200	500	2000
Cadmium	1.0	5	20
Chromium	20	250	800
Cobalt	15	50	300
Copper	30	100	500
Lead	50	500	1000
Mercury	0.1	2	10
Molybdenum	4	10	40
Nickel	20	100	500
Selenium	2	3	10
Silver	2	20	40
Tin	5	50	3000
Zinc	80	500	1500
OTHER INORGANICS			
Bromide (free)	20	50	300
Cyanide (free)	1	10	100
Cyanide (total)	5	50	500
Fluoride (free)	200	400	2000
Sulfur (total)	500	1000	2000
MONOCYCLIC AROMATIC HYDROCARBONS (MAHs)			
Benzene	0.1	0.5	5
Ethylbenzene	0.1	5	50
Toluene	0.1	3	30
Chlorobenzene	0.1	1	10
1,2-Dichlorobenzene	0.1	1	10
1,3-Dichlorobenzene	0.1	1	10
1,4-Dichlorobenzene	0.1	1	10
Xylene	0.1	5	50
Styrene	0.1	5	50
PHENOLIC COMPOUNDS			
Nonchlorinated phenols	0.1	1	10
Chlorophenols (each)	0.1	0.5	5
Chlorophenols (total)	0.1	1.0	10

Exhibit 5
(Continued)

Soil (mg/kg) or (ppm) of dry matter

	A	B	C
POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)			
Benzo(a)anthracene	0.1	1	10
1,2-Benzanthracene	0.1	1	10
Dibenzo(a,h)anthracene	0.1	1	10
Chrysene	0.1	1	10
3-Methylchloanthrene	0.1	1	10
Benzo(b)fluoranthene	0.1	1	10
Benzo(i)fluoranthene	0.1	1	10
Benzo(k)fluoranthene	0.1	1	10
Benzo(g,h,i)perylene	0.1	1	10
Benzo(c)phenanthrene	0.1	1	10
Pyrene	0.1	1	10
Benzo(a)pyrene	0.1	10	100
Dibenzo(a,h)pyrene	0.1	1	10
Dibenzo(a,i)pyrene	0.1	1	10
Dibenzo(a,l)pyrene	0.1	1	10
Indeno(1,2,3-cd)pyrene	0.1	1	10
Acenaphthene	0.1	1	10
Acenaphtylene	0.1	1	10
Fluoranthene	0.1	1	10
Fluorene	0.1	1	10
Naphthalene	0.1	1	10
Phenanthrene	0.1	1	10
PAHs(total)	1	20	200
CHLORINATED HYDROCARBONS			
Aliphatic (total)	0.3	7	70
Chlorobenzene (total)	0.1	4	20
Hexachlorobenzene	0.1	2	10
Polychlorinated biphenyls	0.1	5	50
PESTICIDES			
Pesticides (total)	0.1	2	20
GROSS PARAMETERS			
Mineral oil and grease	100	1000	5000
Light aliphatic hydrocarbons	100	150	800

Case Study: Pacific Place, British Columbia, Canada

Waste Description: The contaminant classes to be addressed at this site include heavy metals, pesticides, PCBs, and petroleum based products. See Exhibit 5 for specific contaminants.

Soil Type: Not provided in documentation.

Depth to Ground Water: Not provided.

Method Description: The Ministry of Environment has established specific criteria for soil and ground water remediatiion based on criteria from various Canadian environmental agencies such as the Canadian Council of Resource and Environmental Ministers, the Province of Quebec, the Ontario Ministry of the Environment, regulatory guidelines such as Canadian drinking water quality guidelines, and pollution control objectives. The Ministry of Environment has established specific criteria for soil and ground water remediation.

As seen in Exhibit 5, three soil levels, A, B and C, are used as investigation and remediation standards for establishing soil cleanup levels. Investigation standards are contaminant concentrations, which when exceeded require detailed investigation to oversee the extent of contamination and nature of the hazard. Remediation standards are contaminant concentrations which when exceeded require action to reduce exposure to potential receptors. The levels are described below.

Level A: This level represents approximate achievable analytical detection limits for organic compounds in soil, and natural background levels of metals and inorganics. For soils with constituents at or less than this level, the soils are considered uncontaminated. For residential land use, level A is the investigation standard.

For soil containing contaminants at concentrations greater than level A, but less than level B, the soil is considered slightly contaminated, but remediation is not required.

Level B: This level is an intermediate value, approximately 5 to 10 times above level A. For residential and recreational land use this level is the remediation standard, while for exclusive commercial or industrial land use it is the investigation standard.

For soil contaminants with concentrations exceeding level B, but less than level C, the soil is considered contaminated, and requires remediation to levels less than level B, if the land is used for residential or recreational purposes. Remediation will not be required if the land is used exclusively for commerical or industrial activities.

Level C: At this level, contamination of soil is significant. For exclusive commerical or industrial land use, level C is the remediation standard. For soils containing contaminants exceeding this level, all uses of the land will be restricted pending the application of appropriate remedial measures, which will reduce contaminant concentrations to levels less than level C.

Data Requirements/Processes Addresses:

- The type and levels of contaminants
- The intended land use of the site after remediation.

Site-Specific Cleanup Goals: The specific cleanup levels for this site have not been established, however, the investigation and remediation standards will be used to define these levels once remediation efforts begin (Exhibit 5).

Site-Specific Method Application: At the Pacific Place site, a thorough investigation of the types and concentrations of contaminants of the site has been completed. The investigation also revealed that the property is intended for mixed residential, commerical, park, and recreational use.

FATE AND TRANSPORT METHODS

Title: **Contaminant Profile Model (ContPro)**

Source: Williams, J.R., T.E. Short, C.L. Eddington and C.G. Enfield, "Contaminant Transport and Fate in Unsaturated Porous Media in the Presence of Both Mobile and Immobile Organic Material," Draft Report, U.S. EPA, Robert S. Kerr Environmental Research Laboratory, Ada, OK, 1988.

Data Requirements/Processes Addressed:

- Initial total concentration of contaminant in system on a mass basis of total sample. Input as depth and concentration.
- Volume fraction of immobile organic phase on a volume basis of total sample. Input as depth and volumetric fraction.
- Initial concentration of mobile organic phase on a mass basis of total sample. Input as depth and concentration.
- Solid:water partition coefficient
- Immobile organic:water partition coefficient
- Mobile, immiscible organic:water partition coefficient
- Vapor:water partition coefficient (dimensionless Henry's Law coefficient)
- Volume fraction of the immobile organic phase (m^3/m^3) on a volume basis of the total sample
- Initial concentration (kg/kg) of the mobile organic phase on a mass basis of the total sample
- Density (kg/m^3) of the solid phase, water phase, immobile organic phase, mobile organic phase and vapor phase
- Total pore fraction, or porosity, of the system (m^3/m^3)
- Half-life (days) for the contaminant in the solid phase, immobile organic phase, mobile organic phase and vapor phase
- Recharge rate at which water is being supplied to the ground water system
- Diffusion coefficient (m^2/day) for the contaminant in the water phase, mobile phase and vapor phase
- Saturated hydraulic conductivity (m/day)
- Clapp-Hornberger constant for the soil being used.

Model Description:

This model was developed as a tool for estimating the transport and fate of chemicals from sites where initial concentrations of contaminants are known as a function of depth. One of the objectives of the model is to provide an estimation of the amount of contamination that will leave the unsaturated zone and enter the ground water. This is accomplished through the calculation of the amount leached. The following description provides a brief overview of the main components of this model.

Transport of contaminants through the following five phases is considered: water, stationary inorganic, immobile organic, mobile organic, and vapor. The mobile organic phase has become a concern because recent research has shown that the partitioning of chemicals between dissolved organic carbon and water may be of considerable importance. In certain disposal situations, the mobile organic phase, in addition to the water phase, flows through the soil, thereby enhancing the mobility of potentially hazardous chemicals, particularly hydrophobic chemicals which are adsorbed to the mobile organic phase. The total concentration of contaminants is composed of contributions from all five phases. The following equation describes this relationship:

$$C_T = (1-n)\,\rho_s C_s + \phi_i \rho_i C_i + \theta_a \rho_a C_a + \phi_m \rho_m C_m + \eta_v \rho_v C_v$$

where: C_T = initial total concentration of the contaminants in the sample (kg/kg)
n = total pore fraction, or porosity, of the system (m^3/m^3)
C = concentrations of the contaminant (kg/kg) in the solid(s), water(a), immobile organic(i), mobile organic(m), and gaseous(v) phases
ρ = densities of the solid(s), water(a), immobile organic(i), mobile organic(m), and gaseous(v) phases in (kg/m^3)
ϕ = volume fraction of the immobile (i) and mobile (m) organic phases in the total sample (m^3/m^3)
θ_a = volume fraction of the water phase in the total sample
η = total pore fraction, or porosity of the system (m^3/m^3).

Independent relationships (R) must be obtained between each of the phases and the total concentrations, thus allowing independent calculation of the concentration of each contaminant in each phase. This can be done by defining five new terms such that:

$$C_T = R_sC_s = R_iC_i = R_aC_a$$
$$= R_mC_m = R_vC_v$$

Assuming linear partitioning and local equilibrium, the R terms can be defined in terms of partition coefficients. Another assumption is that the interface between each of the phases is water and the other phases do not contact each other. Thus, contaminant transfer from one phase to another must include transfer through the water phase. The partition coefficients can be defined as follows:

$$C_s = K_sC_a \qquad C_m = K_mC_a$$
$$C_i = K_iC_a \qquad C_v = K_vC_a$$

where:

K_s = solid:water partition coefficient
K_i = immobile organic:water partition coefficient
K_m = mobile, immiscible organic:water partition coefficient
K_v = vapor:water partition coefficient.

Several methods for determining partition coefficient values are described in Appendix D.

Now the equation can be rewritten in terms of the partition coefficients and the respective phase concentrations. For example, the total soil concentration and the R terms can be expressed as follows:

$$C_T = C_s\,[(1-n)\rho_s + (\phi_i\rho_iK_i + \theta\rho_a + \phi_m\rho_mK_m + \eta_v\rho_vK_v)/K_s]$$

$$R_s = (1-n)\rho_s + (\phi_i\rho_iK_i + \theta\rho_a + \phi_m\rho_mK_m + \eta_v\rho_vK_v)/K_s$$

These equations are formulated for each phase within the source document.

Output Parameters of the Model:

C_s: concentration (kg/kg) of contaminant in the solid phase of the system.

C_a: concentration (kg/kg) of contaminant in the water phase of the system.

C_i: concentration (kg/kg) of contaminant in the immobile organic phase of the system.

C_m: concentration (kg/kg) of contaminant in the mobile organic phase of the system.

C_v: concentration (kg/kg) of contaminant in the vapor phase of the system.

Volatilization losses from the surface of the system.

Total contaminant leached from the soil profile.

Limitations:

The following factors are not addressed:

- Recharge rates
- Hydraulic conductivity - water content relationships
- Depth to ground water
- Spacial and temporal variability of the above parameters.

Case Studies:

Mississippi Wood Treatment, MS.

Title: **Aid for Evaluating the Redevelopment of Industrial Sites (AERIS) model.**

Source: Bulman, T.L., K.R. Hosler, B. Ibbotson, D. Hockley, and M.J. Riddle, "Aid for Evaluating the Redevelopment of Industrial Sites (AERIS) Model," In Development of a Model to Set Cleanup Criteria for Contaminated Soil at Decommissioned Industrial Sites, Environment Canada, Senes Consultants Ltd. and Moneco Consultants Ltd., Canada, 1988.

Data Requirements/Processes Addressed:

- Physical and chemical characteristics of contaminants
- Type(s) of receptor(s) (child or adult)
- Proposed land use
- Site-specific environmental data, including soil characteristics
- Nontoxic threshold levels for contaminants.

Model Description:

This model, currently under development, links exposure assessment (multimedia pathways models) with toxicity assessment as part of an overall risk evaluation procedure. Information about the site being studied, the environmental behavior of a contaminant in site soil and future site use are used in model calculations. The model is enhanced by incorporating information for various Canadian environments, organic and inorganic substances, and algorithms for detailed estimation of transport in the soil system. These include the RITZ and VIP models, currently being developed by the U.S. Environmental Protection Agency. An "expert system" shell is being employed to facilitate the transfer of information between the model user, the model data base and computational procedures. A flow diagram of AERIS model functions is illustrated in Figure 1.

Input screens allow the user to enter site-specific data or to rely on default values which are provided from an internal data base. Input questions relate to the chemical of concern (physical and chemical characteristics), the type of receptor to be studied (adult or child), the proposed land use (residential, agricultural, commercial or recreational) and characteristics of the site environment and soil. The user also can input nontoxic threshold levels, such as levels predetermined by regulation (i.e., guidelines for drinking water).

The AERIS program calculates the concentrations of a pollutant in soil, water, air and plants and the resulting exposure to a human receptor according to the selected land use. Algorithms which evaluate environmental pathways include chemical properties of the pollutant, as well as differential flux equations for mass transfer and flow through porous media. A field study at a petroleum refinery in Nanticoke, Ontario, owned by Texaco Canada, Inc. is being conducted to evaluate model algorithms which could be used as components of the overall AERIS model to improve environmental pathways analysis. The RITZ model currently is being assessed. This model predicts the proportions of a contaminant which will be degraded, volatilized and leached in soil, based on soil and waste characteristics, kinetic parameters of degradation, and volatilization and phase partitioning.

The exposure assessment includes ingestion of dirt and dust, ingestion of produce and field crops, ingestion of drinking water, and inhalation of vapors and particulate matter. Default values are provided for assumptions relating to the ingestion or inhalation of the pollutant for each receptor under various land use scenarios including active and passive behavior, indoors and outdoors, and in winter and summer months. These values can be changed by the user, if desired, to create a site-specific scenario. Risk assessment is performed by calculation of exposures of the receptor and comparison to nontoxic threshold levels. If exposure estimates are greater than nontoxic threshold levels, the estimate of initial soil concentration is reduced and the transport and fate pathways analysis procedure is repeated. The procedure is terminated when concentrations in soil have been identified which could be allowed at the site without exceeding the acceptable exposure levels.

Output for the AERIS model includes a comparison of soil, water, air and plant concentrations with nontoxic threshold levels and predetermined regulatory levels. A comparison of soil concentration with resulting pollutant exposure to a human receptor and the proportion that each exposure pathway contributes to the overall exposure is also provided.

Limitations:

The following factors are not addressed:

- Water movement
- Partitioning between soil, waste water and waste oil
- Diffusion in air and water phases.

Case Studies: None available -- model is still under development.

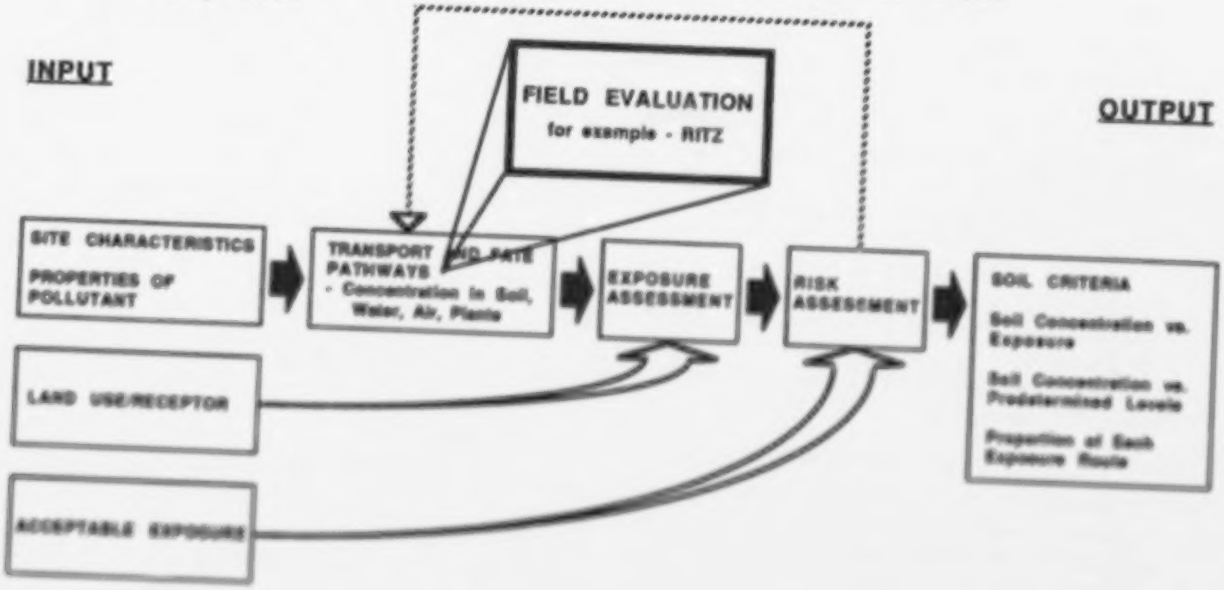

INPUT
OUTPUT
FIELD EVALUATION
for example - RITZ
SITE CHARACTERISTICS
PROPERTIES OF POLLUTANT
TRANSPORT AND FATE PATHWAYS
- Concentration in Soil, Water, Air, Plants
EXPOSURE ASSESSMENT
RISK ASSESEMENT
SOIL CRITERIA
Soil Concentration vs. Exposure
Soil Concentration vs. Predetermined Levels
Proportion of Each Exposure Route
LAND USE/RECEPTOR
ACCEPTABLE EXPOSURE

FIGURE 1.
Flow Diagram of a Method for Selecting Clean-Up Criteria AERIS Model

Title: Decision Tree Process

Source: California Department of Health Services - Toxic Substance Control Division, Site Mitigation Decision Tree Manual, 1986.

Data Requirements/Processes Addressed:

- Initial chemical concentration of infiltration water in the unsaturated zone (mg/l)
- Initial chemical concentration in soil in the unsaturated zone (mg/kg)
- Partition coefficient (mg/l)/(mg/kg)
- Mass of soil per unit volume of soil (kg)
- Fraction of immobile water (pore water)
- Flow rate in horizontal direction from the unsaturated zone $(1^3/t)$
- Flow rate in vertical direction from the unsaturated zone $(1^3/t)$
- Initial chemical concentration in water in the saturated zone (mg/l)
- Chemical concentration entering vertically from the unsaturated zone (mg/kg)
- Mean monthly precipitation or rainfall (ft/yr)
- Mean monthly runoff (l)
- Actual evapotranspiration (l)
- Cross-sectional area of aquifer within cell (ft^2)
- Hydraulic conductivity of aquifer (cm/sec)
- Hydraulic gradient in the aquifer (ft/ft)
- Retardation Factor derived from partition coefficient

Model Description:

This methodology evaluates the movement of chemicals through the unsaturated zone, and is used to estimate the concentrations of organic chemicals in the saturated zone as water infiltrates through an unsaturated soil column. The concentration in the ground water depends on the residual concentration in the soil prior to infiltration.

When estimating potential contaminant concentrations in ground water, advective transport resulting from infiltrating ground water and attenuation must be considered. The Decision Tree Process incorporates a retardation factor based on the carbon and clay content in soils. It is assumed that the unsaturated zone usually has a higher retardation factor than the saturated zone. A record of this calculation was not provided in the documentation.

Following migration, the initial chemical concentration in the infiltrating water (C_w) is calculated from the initial concentration of chemicals in the soil mass using the following relationship:

$$C_w = \frac{C_s}{K_d}$$

where: C_w = initial chemical concentration in water (mg/l)
C_s = chemical concentration in soil (mg/kg)
K_d = partition coefficient [(mg/l)/(mg/kg)]

The equations below were developed to analyze a "batchwise" extraction of chemicals by percolating water from a soil column divided into several cells of equal size. Cell size is determined by factors such as location of cell (i.e., saturated or unsaturated zone) and the limitations of the computer used to run the model. The equations assume that mobile water is replaced by clean water and the system reaches equilibrium with each successive percolating cycle.

The concentration of chemicals leaving the first cell can be expressed as:

$$C_1 = \frac{C_s}{K_d} \quad \frac{(K_d M_s + M_w a)}{K_d M_s + M_w}$$

where: C_1 = concentration of chemicals in water after wetting (mg/l)
M_s = mass of soil per unit volume of soil (kg)
M_w = mass of water per unit volume of soil assuming 50% moisture content (kg)
a = fraction of immobile water

The chemical concentration in the water leaving the second cell can be expressed as:

$$C_{w2} = \frac{C_{w2}^{*}\ (M_s K_d + M_w) - C_{w1} M_w (1-\alpha)}{M_s K_d + M_w \alpha}$$

where: C_{w2} = concentration of chemicals in water leaving cell 2 (mg/l)
C_{w1} = concentration of chemicals in water entering cell 2 from cell 1 (mg/l)
C_{w2}^{*} = concentration of chemicals in water in cell 2 after one pore volume flush (mg/l)

Water leaving cell 2 enters cell 3. This methodology, as mentioned earlier, uses a "batchwise" extraction of chemicals from a soil column. The resulting chemical concentration leaving the last cell is the concentration at the unsaturated-saturated boundary.

Upon entering the saturated zone the chemical concentrations are attenuated by the higher flow rates. The method also assumes that total mixing of chemicals occurs as water is leached out of the unsaturated zone. The amount of attenuation is calculated by using relative flow rates and chemical concentrations entering and leaving a control volume.

$$C_H^{\dagger} = \frac{(Qin)_H\ C_H + (Qin)_v\ C_v}{(Qin)_H + (Qin)_v}$$

where: $C_H^{\dagger}$ = resulting attenuated chemical concentration in the saturated zone (mg/kg)
C_H = initial chemical concentration in the saturated zone (mg/kg)
$(Qin)_H$ = flow rate entering the control volume in horizontal direction, from the unsaturated zone (l^3/t)
$(Qin)_v$ = flow rate entering the control volume in the vertical direction; from the unsaturated zone (l^3/t)
C_v = chemical concentration entering the control volume vertically from the unsaturated zone (mg/kg)

Two additional calculations are needed, percolation rate and dilution factor, to complete the evaluation of the chemical concentration in the unsaturated zone compared to the estimated chemical concentration in the aquifer.

The percolation fraction of precipitation is the principle contributor to chemicals leaching from the unsaturated zone. The equation to calculate monthly water balance or mean percolation is:

$$PERC = P - R/O - \Delta ST - \Delta ET$$

where: $PERC$ = mean monthly percolation (ft/yr)
P = mean monthly precipitation or rainfall (1)
R/O = mean monthly runoff (1)
ΔST = change in soil moisture storage (1)
ΔET = actual evapotranspiration (1)

The last measurement needed to compute the expected aquifer concentration is the dilution factor (DF), which is defined:

$$DF = \frac{(Qin)v}{[Qin)_H + (Qin)_v]}$$

where: $(Qin)v = Av \times PERC$
Av = the horizontal cross-sectional area of the control volume in the saturated zone (ft^2)

The flow rate entering the control volume in the horizontal direction from the unsaturated zone, $(Qin)_H$, is defined as:

$$(Qin)_H = A_H \times K_H \times i$$

where: A_H = cross sectional area of the aquifer (ft^2)
K_H = hydraulic conductivity of the aquifer (cm/sec)
i = hydraulic gradient in the aquifer (ft/ft)

After obtaining the dilution factor and the chemical concentration at the saturated-unsaturated zone boundary, the predicted concentration of the chemical in the aquifer can now be calculated:

Aquifer Concentration = Concentration at saturated-unsaturated boundry x DF

This equation is an estimate of the of the resultant chemical concentration at the point of exposure, given the initial chemical concentration in the soil in the unsaturated zone.

Limitations:

- Requires extensive and sometimes difficult to obtain field measurements

- Vertical movement through the unsaturated zone and into the ground water is assumed

- Total mixing of chemicals upon leaving unsaturated zone is assumed

- Batchwise system assumes soil column is flushed with clean water.

Case Studies:

Intel, CA; Rathon, CA; and Fairchild, CA - collectively known as the Mt. View, CA, site.

Title: Ground Water Contamination from Sewage Sludge

Source: 40 CFR parts 257 and 503, Monday, February 6, 1989, Standards for the Disposal of Sewage Sludge; Proposed Rule.

Data Requirements/Processes Addressed:

- Electromotive potential of soil
- pH of onsite soil
- Leachate pulse rate (years)
- Metal concentration in sludge (mg/kg)
- Sludge solids content (kg/l)
- Fill thickness (meters)
- Assumed leachate concentration
- Ground water recharge rate (m/yr)
- Amount of excess liquid in sludge (l/yr)

Model Description:

EPA has adapted existing models to determine the concentration of sludge-borne contaminants in ground water. Two waste application scenarios were considered in the EPA methodology discussed below:

- land applications for agriculture
- wastes placed in a sludge-only landfill.

For both application scenarios and subsequent contaminant pathways a series of mathematical models was used to predict the contaminant concentration at the point of exposure. Models, CHAIN, MINTEQ, and AT123D were used consecutively to predict the contaminant flow through the unsaturated zone, the unsaturated zone/saturated zone interface and the saturated zone. Applicable components of these models will be further described in this summary. Because this compendium addresses contaminant migration through the unsaturated zone, only these evaluation components of this EPA method will be summarized below.

The leachate concentration formed in the soil layer containing the sludge is related to the contaminant concentration in the soil using a partition coefficient. In the unsaturated zone, the peak leachate concentration is reduced by the modeled processes of vertical dispersion (primarily caused by detention of sorbed contaminants), natural chemical degradation, and metal precipitation. The CHAIN model was used to predict these processes for organics, and the geochemical model, MINTEQ, for metals. Factors affecting the contaminant loading rate in the unsaturated zone include the recharge or infiltration rate, hydraulic characteristics of the soil, depth to ground water, and the partition-coefficient. For some metals, the net ground water electromotive potential (Eh) and pH also influence precipitation rates.

The exposure pathway examined by EPA was contaminant infiltration to ground water and subsequent ingestion via drinking water. The analytical framework for the ground water model contained four components:

- a calculation of contaminated leachate pulse duration (contaminant release to the unsaturated zone)
- a model of contaminant behavior and movement in the unsaturated zone
- an evaluation of metal solubility in ground water
- a model of contaminant behavior and movement in the saturated zone.

The analysis includes assumptions on the size and thickness of landfills, the concentration of the contaminant in the sludge, the contaminant concentration in the leachate, and the net recharge or infiltration rate.

First, the leachate pulse rate or the time in which the landfill releases a metal pollutant to the unsaturated zone is calculated for metals:

$$T = (CS \times SS/CL) - EL \times D/R$$

where: T = time (years)
CS = metal concentration in sludge (mg/kg)
SS = sludge solids content (kg/l)
D = fill thickness (meters)
CL = assumed leachate concentration (mg/l)
R = ground water recharge rate (m/yr)
EL = excess liquid in original sludge (l/yr)

The EL term adjusts the recharge water rate based on the sludge characteristics (i.e., aqueous). The organic contaminants in the above calculations are modified to account for decay. This modification is described in the EPA's "Land Application and Distribution and Marketing of Sewage Sludge." In contrast, the calculation above assumes that the (CL) leachate concentration remains constant until the sludge is completely depleated of the contaminant, thereby modeling the leachate pulse as a mathematical square wave.

This leachate pulse is subsequently used in the unsaturated zone CHAIN model. The CHAIN model (Van Genuchten, 1985) assumes a steady rate of percolation through the unsaturated zone. This model calculates the contaminant concentrations in the leachate as affected by sorption to the soil and decay (of organic contaminants).

These modified leachate pulse levels (i.e., metals, organics) are further adjusted for solubility constraints, based on the calculations of MINTEQ (Felmy, 1984). This incorporates the results of previous runs at various conditions of pH and Eh.

The estimated contaminant leachate entering the aquifer beneath the monofill is then applied to the saturated zone fate and transport model, AT123D (Yeh, 1981). This model calculates the contaminant plume considering advection, diffusion and dispersion, sorption, decay, and for landfills, the distance from the sewage sludge unit to the property boundary of the landfill or 150 meters, whichever is less.

The components of the EPA models (leachate pulse, CHAIN, MINTEQ, and AT123D) are run through trial and error and to determine the sludge concentration equal to the MCL or allowable drinking water standard at the point of compliance.

Limitations:

Several uncertainties and assumptions must be considered when using the model's predictions. These include:

- Sludge pollutants solubilized (leached) if not first degraded
- Square wave input to ground water
- Organic pollutant decay rate

Additional assumptions and derivations to the model is further discussed in "Landfilling Sewage Sludge," (US EPA, 1988). These identify applications for differing exposure pathways.

Output Parameters of the Model:

- Leachate pulse rate (years)
- Contaminant plume dimensions
- Leachate contaminant concentrations, based on sludge concentrations, that will be equal to or below MCLs or allowable drinking water standards

GENERIC METHODS

Title: **Designated Level Methodology**

Source: California Regional Water Quality Control Board, "Waste Classification and Cleanup Level Determination Draft Guidance Document," Central Valley Region, 1985.

Data Requirements/Processess Addressed:

- Water quality goals, such as background levels or accepted criteria and standards
- Environmental attenuation and bioavailability data for contaminants

Model Description:

The California State Water Resource Control Board has established a waste classification scheme and developed cleanup criteria based on the threat that these wastes (including contaminated soil) pose to the beneficial uses of waters of the State. The designated waste category, comparable to the California Department of Health Services (DHS) hazardous waste classification, is described as the level at which a waste could significantly impair water quality. To more clearly define the lower boundary of the classification, the Designated Levels methodology was developed. This methodology was derived from the California Assessment Manual for Hazardous Waste Final Statement of Reasons (CAM SOR), for the Hazardous Waste Identification Regulations adopted by DHS in 1984.

The Designated Level methodology was developed to provide a means for determining if a solid waste is hazardous and the appropriate type of waste management unit. Because contaminated soil and wastes in an unlined landfill, surface impoundment or waste pile pose a similar threat to water quality, the Designated Level methodology also can be used to establish contaminated soil cleanup levels. By using this methodology, soil brought to a cleanup level at or below the Designated Level calculated for a particular contaminant can be considered protective of nearby surface or ground water quality.

Designated Levels can be calculated for specific contaminants and at specific sites by determining appropriate water quality goals, such as background water concentrations or accepted criteria and standards, and then applying factors to account for environmental attenuation and bioavailability. Contaminant concentrations that are less than these calculated levels are not considered to be a detriment to the beneficial uses of the waters of the State, and, therefore, can be disposed in an unlined landfill. Wastes containing contaminant concentrations in excess of the Designated Levels are classified as "designated wastes" and must be disposed of in waste management unit that isolates them from the environment (e.g., lined landfill). Designated wastes have the potential to be mobilized and transported to ground and/or surface waters in amounts that could degrade the quality of those waters.

The attenuation factor chosen for the Designated Level methodology is the one recommended by the CAM SOR. It is a 100-fold attenuation factor and is based on studies conducted by Battelle Laboratories and the U.S. EPA. The EPA study used a mathematical model in formulating its 100-fold factor, examining attenuation factor data from several known disposal sites ranging in values from 6 to greater than 1,000 for various toxic substances. Both studies indicate that the degree of attenuation is dependent on the chemical properties of the waste constituents, distance from the waste management unit to usable water, the geologic materials including the permeability, chemistry and structure, and the velocity of ground or surface water. Therefore, it would be difficult to select a factor that would be appropriate for all contaminants and disposal situations. A factor of 100 is considered to conservatively represent average attenuation of waste contaminants as they leach from soil into ground water. Where site conditions indicate the probability of limited attenuation, such as highly permeable soil or shallow depth to ground water, an attenuation factor less than 100 should be used. In the case where contaminants exhibit a strong capacity for attenuation, a factor higher than 100 should be chosen. For example, the Designated Level Methodology uses a 1,000-fold attenuation factor for copper, zinc, and DDT because these constituents are known to be highly immobile in soil.

Note that specific attenuation factors are not assigned for individual contaminants. Decisions to adjust the attenuation factor are based on assumptions pertaining to contaminant and site characteristics.

Water Quality goals to be used in deriving Designated Levels can come from several sources. Background water quality, is an appropriate goal in some cases, however, there are many sources of numerical criteria which were established to protect human health and the environment. A list containing several of these sources can be found in Appendix E.

Designated Levels for contaminated soils can be expressed as Soluble or Total. The extractable or soluble fraction of a contaminant in soil is what actually has the potential for migration; therefore, the Soluble Designated Level (SDL) more accurately measures the ability of a contaminated soil to degrade water quality. When calculating the SDL, it is assumed that by the time the leachate reaches and combines with ground water, the concentrations of soluble constituents have been diminished by a factor equal to the environmental attenuation factor (i.e., 100, 1000). Additionally, the concentrations in the initial leachate is assumed to be equal to the extractable concentration in the contaminated soil prior to leaching. Thus, the SDL can be expressed in mg/kg as:

$$\begin{array}{c}\text{Soluble}\\ \text{Designated Level}\\ \text{(mg/kg of waste)}\end{array} = \begin{array}{c}\text{Environmental}\\ \text{Attenuation Factor}\end{array} \times \begin{array}{c}\text{Water Quality}\\ \text{Goal (mg/l)}\end{array}$$

The extractable or soluble fraction of a contaminant in a soil or solid waste sample can be obtained by performing a leachate extraction procedure on the sample. The California Waste Extraction Test (WET) is the leachate test procedure recommended for this method. (For a detailed description of the WET, see Appendix C). It requires a ten-fold dilution of solid waste into a buffered citric acid extract solution, resulting in a concentration of 1 mg/l of extract that is equivalent to 10 mg/kg of waste. The SDL, expressed as mg/l of extract, is equal to one tenth the SDL expressed as mg/kg of waste:

$$\begin{aligned}\text{Soluble Designated Level (mg/l of extract)} &= \frac{\text{Soluble Designated Level (mg/kg of waste)}}{10}\\ &= \frac{\text{Environmental Attenuation Factor}}{10} \times \text{Water Quality Goal (mg/l)}\end{aligned}$$

It is important to note that other leachate test procedures may not require the same amount of dilution as in WET, and, therefore, a different dilution factor would be used in the equation above.

Total Designated Levels (TDLs) should be calculated when extractable contaminant concentrations in a soil cannot be determined but total contaminant concentration analysis in a soil is possible. The results of the total concentration analysis is compared to the TDL for a specific contaminant to determine if the degree of contamination in the soil is exceeding the recommended cleanup level. TDLs can be derived from SDLs by applying a bioavailability factor that represents the soluble fraction of the total contaminant concentration which can move into the leachate and migrate to ground or surface waters. This methodology employs a generic bioavailability factor of 100 for inorganic constituents and 10 organic constituents. Note that bioavailability factors should be adjusted to compensate for site or chemical specific conditions. For instance, a higher bioavailability factor may be appropriate if the physical and chemical properties of a particular contaminant decreases the potential for leaching. TDLs are expressed in mg/kg of waste as:

Inorganics:

$$\text{Total Designated Level (mg/kg of waste)} = 100 \times \text{Soluble Designated Level (mg/kg of waste)}$$

Organics:

$$\text{Total Designated Level (mg/kg of waste)} = 10 \times \text{Soluble Designated Level (mg/kg of waste)}$$

When using SDLs expressed in mg/l of extract, due to the 10-fold dilution in WET, the attenuation factors above would be: inorganic, 1000; and organic, 100. Here again, the dilution factor depends on the amount of dilution used in the leachate extraction procedure selected.

Another component of the Designated Level Methodology for determining contaminated soil cleanup levels is consideration of cumulative environmental/health effects. When several contaminants with similar properties or toxicologies are present, it is presumed that their effects are additive. The contaminated soil can be considered to meet the appropriate cleanup levels if the sum of the quotients (obtained by dividing the concentration of each contaminant identified and its recommended Designated Level) is less than one. This equation is expressed as:

$$\sum_{i=1}^{n} \frac{(\text{chemical concentration})_i}{(\text{chemical Designated Level})_i} < 1.0$$

Calculating cumulative effects is a more conservative method for determining soil cleanup levels because it considers more than one contaminant in the soil. This is demonstrated by the fact that the sum of the quotients in the equation above can be greater than one and, therefore, it exceeds the recommended cleanup level even if each contaminant is below its individual Designated Level.

The method used to determine the appropriate soil performance goal may be selected based on several factors. These include the frequency and type of contaminants (i.e., VOCs, inorganics), geologic characteristics and estimated risk at the site.

Limitations:

- Site-specific considerations not addressed in detail.

Case Studies:

PG&E-Caribou Power House, PCB spill, Plumes County, CA; Lawrance Livermore National Laboratory, Nameda, CA; and Southern Pacific, Roseville, Placid County, CA.

Title: Acceptable Soil Contamination Levels

Source: New Jersey Department of Environmental Protection, "Acceptable Soil Contamination Levels Methodology," In Inventory of Criteria and Methods to Select Criteria, (Unpublished Report), G.M. Richardson, Environment Canada, 1987.

Data Requirements/Processes Addressed:

- For organic contaminants, certain site-specific characteristics, including soil:water partition coefficients; measures of chemical mobility, erosion, and topography
- EPA water quality criteria, drinking water standards, acute toxicity or other data for organic contaminants.

Method Description:

Under the Environmental Cleanup Responsibility Act (ECRA), the New Jersey Department of Environmental Protection has determined Acceptable Soil Contamination Levels (ASCLs) for 11 metals and 4 classes of organic compounds. The goal of these soil criteria is to protect ground water quality. Acceptable levels of inorganic contaminants represent simple multiples of background levels of these contaminants in New Jersey or other U.S. soils.

Acceptable concentration levels of organic compounds are obtained by using a system that addresses the three media; soil, ground water and surface water. The system includes the prediction of contaminant distribution between the three types of media using certain site-specific characteristics, including soil:water partition coefficients, measures of chemical mobility, erosion, and topography. These characteristics are combined with EPA water quality criteria, drinking water quality guidelines and acute toxicity or other data to calculate ASCLs which are then used to guide cleanup. In the absence of data required to determine ASCLs for organics, the following surrogate or action levels are used: volatile organics - 1 ppm total in soil; base/neutrals - 10 ppm total in soil; petroleum hydrocarbons - 100 ppm total in soil (except benzene and PAHs).

This method is simple, requires a minimal amount of input data, and focuses primarily on soil contamination.

Limitations:

The method does not address multi-contaminant and multimedia exposure, or inhalation or dermal exposure to contaminants.

Case Studies:

Burnt Fly Bog, NJ (for lead and PCBs only)
Ringwood Mines, NJ (lead and arsenic)

Title: **Maximum Exposure Dosage (MED 200)**

Source: Contaminated Soils Workgroup Preliminary Findings and Recommendations, (Draft), Maximum Exposure Dosage (MED 200) Methodology.

Data Requirements/Processes Addressed:

- EPA drinking water standards for metals and pesticides.

Method Description:

The MED 200 method is designed for use by the Emergency Response Team (ERT) and the individual EPA Regions for emergency actions. It involves the removal of onsite soils until metals or pesticides are at 200 times drinking water standards (e.g., chromium standard would be 10 ppm for soils). This approach assumes that it is unlikely that metals or pesticides would contaminate ground water at significant levels.

One advantage of this method is that direct contact threats are addressed because contaminants posing potential immediate hazards are removed. It also considers ground water protection through use of drinking water standards. In addition, analytical results can be obtained simply and quickly because the method involves only a total contaminant concentration analysis and does not include time intensive procedures such as the gathering of site-specific soil and hydrogeologic information required when conducting fate and transport modeling.

Limitations:

- Potential for overprotective measures in many situations
- Parameters such as low mobility are not considered
- Does not address contaminants other than metals and pesticides.

Case Studies:

This method is used exclusively as a reference tool to establish soil cleanup levels and supported by additional site-specific parameters such as risk factors and exposure levels.

Title: **Technical Cleanup Policy**

Source: Washington State Department of Ecology, "Standard/Background Cleanup Level and Protection Cleanup Level Methodologies," In Inventory of Cleaning Criteria and Methods to Select Criteria, (Unpublished Report), G.M. Richardson, Industrial Programs Branch, Environment Canada, 1987.

Data Requirements/Processes Addressed:

- Standard or background levels for contaminants, such as drinking water or water quality standards, water quality background levels, and/or soil background levels
- Certain site-specific data, including contaminant, hydrologic, and soil characteristics.

Method Description:

The Cleanup Policy developed by the State of Washington is based on three types of cleanup levels: initial, standard/background, and protective cleanup levels for soil, surface water, ground water, and air. Cleanup criteria are based on existing environmental standards such as EPA Water Quality Criteria or drinking water guidelines; in the absence of appropriate standards, criteria are based on background levels of contaminants. Initial cleanup levels are intended to eliminate all imminent threats to public health and the environment, and to eliminate situations where a delay will increase the difficulty of cleanup.

Remedial options include total cleanup, partial cleanup, site stabilization, or a combination of partial cleanup and site stabilization, depending on the site conditions. Standard/background cleanup levels are applied to all sites where an initial total cleanup option is not implemented; these cleanup levels are intended to eliminate any potential chronic threat to public health or the environment. Standard/background cleanup levels for soil are 10 times the drinking water or water quality standards, 10 times the water quality background levels, or equal to the soil background levels. If standard/background cleanup levels are not appropriate or can not be achieved, the site is subjected to soil Protection Cleanup Levels or the maximum acceptable concentration of soil contamination at the source, that are derived either from existing standards or from predictive models (types of models unspecified), using site-specific data.

For contaminated soil that is a potential threat to surface or ground water quality, Protection Cleanup Levels are designated 100 times the drinking water or water quality standards, 100 times the water quality background levels, 10 times the soil contaminant background levels, or are defined based on site-specific contaminant and soil characteristics, leaching tests or biologic tests. If sufficient site-specific input data are available, predictive models, including HELP and SUTRA, may be used to determine soil Protection Cleanup Levels as follows.

First, the maximum acceptable level of contamination in the ground water directly underlying the contaminant source is defined, using the appropriate water quality standards or water quality background levels, biologic testing, or the ground water protection level (the maximum acceptable concentration in the ground water). Next, the maximum acceptable concentration gradient is defined with verified transport models, using site-specific contaminant, hydrologic, and soil characteristics; the concentration gradient is then used to determine the soil Protection Cleanup Level.

Limitations:

This method is limited to use at sites contaminated with chemicals for which environmental standards exist. In addition, the method does not address multi-contaminant and multimedia exposure.

Case Studies:

This method is used as an initial site evaluation tool and has not been used as an exclusive source to establish soil cleanup levels.

BIBLIOGRAPHY

1) American Conference of Governmental Industrial Hygenists, "Documentation of the Threshold Limit Volumes," 4th ed., American Conference of Governmental Industrial Hygenists, Cincinnati, OH, 1980

2) Bates, R.L. and J.A. Jackson, eds., Dictionary of Geological Terms, 3rd Ed. Anchor Press/Doubleday, Garden City, NY, 1984.

3) Brady, N.C., The Nature and Properties of Soils, 9th Ed., Macmillan, New York, NY, 1984.

4) Briggs, G.G., R.H. Bromilow, A.A. Evans, "Relationships Between Lipophilicity and Root Uptake and Translocation of Non-ionized Chemicals by Barley", Pesticide Science, 13, pp. 495-504, 1982.

5) Bulman, T.L., K.R. Hosler, B. Ibbotson, D. Hockley, and M.J. Riddle, "Aid for Evaluating the Redevelopment of Industrial Sites (AERIS) Model", In Development of a Model to Set Cleanup Criteria for Contaminated Soil at Decommissioned Industrial Sites, Environment Canada, Senes Consultants Ltd. and Moneco Consultants Ltd., Canada, 1988.

6) California Department of Health Services - Toxic Substance Control Division, Site Mitigation Decision Tree Manual, 1986.

7) California Regional Water Quality Control Board, "Waste Classification and Cleanup Level Determination Draft Guidance Document", Central Valley Region, 1985.

8) CH_2M Hill, "Soil Contaminant Evaluation Methodology (SOCEM I)", In Guidance on Remedial Actions for Contaminated Soils at CERCLA Sites, (Draft), Groundwater, May-June edition, 1985.

9) Clapp, R.B. and G.M. Hornberger, "Empirical Equations for some Hydraulic Properties", Water Resources Research, V. 14, pp. 601-604, 1978.

10) Cleland, J.G., G.L. Kingsbury, "Mutimedia Environmental Goals for Environmental Assessment," Vol. I, EPA 600/7-77-136a, Environmental Protection Agency, Washington, DC, pp. 60-61, November 1977

11) Contaminated Soils Workgroup, "Preliminary Findings and Recommendations (Draft)", Background Levels Methodology.

12) Contaminated Soils Workgroup, "Preliminary Findings and Recommendations (Draft)", Exposure Assessment Using Leachate Tests Methodology.

13) Contaminated Soils Workgroup, "Preliminary Findings and Recommendations (Draft)", Maximum Exposure Dosage (MED 200) Methodology.

14) Contaminated Soils Workgroup, "Preliminary Findings and Recommendations (Draft)", Visibly Contaminated Soils Methodology.

15) Dragun, J., The Soil Chemistry of Hazardous Materials, Chapter 6, Table 6.4 1988.

16) Felmy, A.R., D.C. Girvin and E.A. Jenne, "MINTEQ - A Computer Program for Calculating Aqueous Geochemical Equilibrium", EPA-600/3-84-032, 1984

17) Fetter, C.W. Jr., Applied Hydrogeology, Charles E. Merrill/Bell and Howell, Columbus, OH, 1980.

18) Fitchko, J., Criteria for Contaminated Soil/Sediment Cleanup, 1989

19) Freeze, R.A. and J.A. Cherry, Groundwater, Prentiss Hall, Englewood, NJ, 1979.

20) Holt, G.A., C.C. Travis, E.L. Etnier, C. Cook, F.R. O'Donnell, D.M. Hedrick and E. Dixion. "Multiple Pathway Screening - Level Assessment of a Hazardous Waste Incineration Facility," ORNL/TM-8652, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1984.

21) Hunt, B., "Dispersive Sources in Uniform Groundwater Flow", Journal of the Hydraulics Division, ASCE, V. 104, pp. 75-85. 1978.

22) ICF/Clement Associates, "Final Focused Feasibility Study - Independant Nail Company Site - First Operable Unit", Beaufort, South Carolina, 1988, DC #237-FS1-RT-FSAC.

23) Neiburger, M., J.G. Edinger, and W.D. Bonner, Understanding Our Atmospheric Environment, 2nd Ed., W.H. Freeman and Co., San Francisco, CA, 1982.

24) New Jersey Department of Environmental Protection, "Acceptable Soil Contamination Levels Methodology", In Inventory of Criteria and Methods to Select Criteria, G.M. Richardson, Environment Canada, 1987.

25) Rosenblatt, D.H., J.C. Dacre and D.R. Cogley, "An Environmental Fate Model Leading to Preliminary Pollutant Limit Values for Human Health Effects", In Environmental Risk Analysis for Chemicals, Chapter 15, pp. 474-505, 1982.

26) Rosenblatt, D.H., M.J. Small and R.J. Karnz, "Application of the Preliminary Pollutant Limits (PPLV) Environmental Risk Assessment Approach to Selected Land Users", In Fate of Chemicals in the Environment, ACS Symposium Series, Washington, D.C. 1983.

27) Salee, Mark A. (Memo), Land Disposal Branch, USEPA, to Kenneth A. Shuster, Chief of Land Disposal Branch USEPA, Oct. 24, 1984.

28) Sanders, J.E., Principle of Physical Geology, John Wiley & Sons, New York, NY, 1981.

29) Summers, K., S. Gherini and C. Chen, Tetra Tech Inc., "Methodology to Evaluate the Potential for Groundwater Contamination from Geothermal Fluid Releases", EPA-600/7-80-117, 1980.

30) Synder, W.S., "Report of the Task Group on Reference Man", International Commission on Radiological Protection, No. 23, New York, Pergamon Press, 1975.

31) U.S. Army, "Single Pathway Preliminary Pollutant Limit Values and Preliminary Pollutant Limit Values (SPPPLV and PPLV)", In Inventory of Cleaning Criteria and Methods to Select Criteria, An unpublished document, G.M. Richardson, Industrial Programs Branch, Environment Canada, 1987.

32) U.S. Congress, Office of Technology Assessment, "Superfund Strategies for Setting Cleanup Goals," In Inventory of Cleanup Criteria and Methods to Select Criteria, G.M. Richardson, Environment Canada, 1987.

33) U.S. EPA, "Evaluating Cover Systems for Solid and Hazardous Waste", EPA SW-867, 1982.

34) U.S. EPA, "Guidance for Establishing Target Cleanup Levels for Soils at Hazardous Waste Sites", Office of Health and Environmental Assessment, Washington, D.C., 1988.

35) U.S. EPA, Interactive Simulation of the Fate of Hazardous Chemicals During Land Treatment of Oily Wastes: RITZ User's Guide, Robert S. Kerr Environmental Research Laboratory, Ada, OK, 1988.

36) U.S. EPA, "National Interim Primary Drinking Water Regulations", Federal Register 40, pp. 59565-59588. December 24, 1975.

37) U.S. EPA, Office of Solid Waste, OSW Studies and Methods Branch Model, In Attachment A of Summary of Remedial Alternative Selection, McKin Company Site-Gray, ME: Analysis of Property Boundary Contaminant Concentrations, Camp, Dresser and McKee, 1985.

38) U.S. EPA, "Radionuclide Interactions with Soil and Rock Media", EPA report 5206-78-007, Vol. 1, 1987.

39) U.S. EPA, "Technical Support Document: Landfilling of Sewage Sludge" (Draft), Washington, DC, 1988

40) U.S. EPA, Technical Support Document: Land Application and Distribution and Marketing Sewage Sludge (Draft). Office of Waste Regulations and Standards, Washington, DC, 1988.

41) U.S. EPA, "Waste Quality Criteria Documents: Availability 45 Federal Regulations 79318-79379", U.S. Environmental Protection Agency, Washington, D.C. 1980.

42) Van Genuchten, M., "Convective-Dispersive Transport of Solutes Involved in Sequential First-Order Decay Reactions", Journal of Computer Geoscience, Vol. 11 (129) (CHAIN), 1985.

43) Vettorazzi, G., "The Evaluation of Toxicological Data for the Protection of Public Health;" Proceedings Inst. Colloq. Commission of the European Committee; Luxenburg, pp. 207-223, 1976.

44) Washington State Department of Ecology, "Standard/ Background Cleanup Level and Protection Cleanup Level Methodologies", In Inventory of Cleaning Criteria and Methods to Select Criteria, G.M. Richardson, Environment Canada, 1987.

45) Williams, J.R., T.E. Short, C.L. Eddington and C.G. Enfield, "Contaminant Transport and Fate in Unsaturated Porous Media in the Presence of Both Mobile and Immobile Organic Material", (Draft), U.S. EPA, Robert S. Kerr Environmental Research Laboratory, Ada, OK, 1988.

46) World Health Organization, "Evaluation of the Toxicity of a Number of Antimicrobials and Antioxidants", Sixth Report of the Joint FAO/WAO Expert Committee on Food Additives, WHO Tech, Rep. Ser. No. 228, pp. 9-11. 1962.

47) Yeh, G.T., "AT123D: Analytical Transient One-, Two-, and Three- Dimensional Simulation of Waste Treatment in the Aquifer System", Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, ORNL-5602 1981.

POTENTIAL REFERENCES

Anderson, P.F., C.R. Faust, and J.W. Mercer, "Analysis of Conceptual Designs for Remedial Measures at Lipari Landfill, NJ", Ground Water V. 22, No. 2, pp. 176-190, 1984.

Assink, J.W., and W.J. Van der Brink, eds., "Contaminated Soil", In *Proceedings from the First International TNO Conference on Contaminated Soil*, November 11-15, 1985, Utrecht, The Netherlands, Dordrecht, The Netherlands, Martinus Nijhoff Publishers, 1986.

Baehr, A.L., "Selective Transport of Hydrocarbons in the Unsaturated Zone Due to Aqueous and Vapor Phase Partitioning", Water Resources Research, V. 23 No. 10, pp. 1926-1938, 1987.

Brown, H.S, "A Critical Review of Current Approaches to Determining "How Clean is Clean" at Hazardous Waste Sites", Hazardous Waste and Hazardous Materials, 3(3) pp. 233-260, 1986.

Brown, K.W., "Monitoring the Unsaturated Zone" In *Land Treatment: A Hazardous Waste Management Alternative*, Water Resources Symposium Number Thirteen, Centre for Research in Water Resources, The University of Texas at Austin, Texas, 1986.

Bond, F.W., C.R. Cole, and P.J. Gutkecht, "Unsatured Groundwater Flow Model (UNSATID) Computer Code Manual", EPRI CS-2434, Electric Power Research Institute, Palo Alto, California, 1982.

Caupp, C.L., W.J. Grenney and P.J. Ludvigsen, "VIP: A Model for the Evaluation of Hazardous Substances in the Soil, Version 2", Department of Civil and Environmental Engineering, Utah State University, Logan, Utah, 1987.

Collins, J.O. and P.C. LeClare, "Risks, Costs and Public Policy: Determining Acceptable Cleanup Levels", In *Conference on Management of Uncontrolled Hazardous Waste Sites*, pp. 398-400, 1983.

Dacre, J.C., D.H. Rosenblatt and D.R. Cogley, "Preliminary Pollutant Limit Values for Human Health Effects", Evironmental Science and Technology, 14(7), pp. 778-784, 1980.

Dass, P., G.R. Tamke, and C.M. Stoffel, "Leachate Production at Sanitary Landfills", Journal Environmental Engineering Division, *Proceedings of the American Society of Civil Engineers*, V. 103, No. EE6, 1977.

Dawson, G.W. and D. Sanning, "Exposure - Response Analysis for Setting Site Restoration Criteria", In *Proceeedings of the National Conference on Management of Uncontrolled Hazardous Waste*, pp. 386-389, 1982.

Dime, R. and W. Greim, "Calculation of Cleanup Levels for Contaminated Soils", Hazardous Sites Mitigation Administration, New Jersey Department of Environmental Protection, 1986.

Fenn, D.G., K.J. Hanley, and T.V. Degeare, "Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites", SW-168, U.S. Environmental Protection Agency, Washington, D.C., 1975.

Gelhar, L.W. and C.L. Axness, "Three-Dimensional Stochastic Analysis of Macrodispersion in Aquifers", Water Resources Research, V. 19, No. 1, pp. 161-180, 1983.

Grisham, J.W., ed., Health Aspects of the Disposal of Waste Chemicals, New York, Pergamon Press, 1986.

Hwang, S.T., Technical Support Document Mathematical Model Selection Criteria for Performing Exposures Assessment: Airborne Contaminants from Hazardous Waste Facilities, Office of Health and Environment Assessment, Office of Research and Development, U.S. EPA, Washington, D.C., 1986.

Ibbotson, B.G., D.M. Gorber, D.W. Reades, D. Smyth, I. Munro, R.F. Willes, M.G. Jones, G.C. Granville, H.J. Carter and C.E. Hailes, "A Site-Specific Approach for the Development of Soil Clean-up Guidelines for Trace Organic Compounds", In Proceedings for the 2nd Conference on Environmental and Public Health Effects of Soils Contaminated with Petroleum Products, University of Massachussets, Amherst, Massachusetts, 1987.

Jaber, H.M., et al., "Data Acquisition For Environmental Transport and Fate Screening For Compounds of Interest to the Office of Emergency and Remedial Response", U.S. EPA, Washington, D.C., EPA 600/6-84-011, 1984.

Kenaga, E.E., and C.A.I Goring, "Relationship Between Water Solubility, Soil Sorption, Octanol-Water Partitioning, and Concentration of Chemicals in Biota", Aquatic Toxicology, American Society for Testing and Materials, ASTM STP 707, pp. 78-115, 1980.

Life Systems, Inc., Toxicology Handbook: Principles Related to Hazardous Waste Life Investigations, U.S. EPA, 1985.

Lyman, W., W. Reehl, and D. Rosenblatt, Handbook of Chemical Property Estimation Methods, McGraw-Hill, New York, 1982.

Moghissi, A.A., R.R. Marland, F.J. Congel, and K.F. Eckerman, "Methodology for Environmental Human Exposure and Health Risk Assessment", In Dynamics, Exposure, and Hazard Assessment of Toxic Chemcials, Ann Harbor Science, Chapter 31, 1980.

National Research Council, Testing for Effects of Chemicals on Ecosystems, Washington, D.C., National Academy Press, 1981.

Neely, W.B. and G.E. Blau, Environmental Exposure from Chemicals, CRC Press Inc., Boca Raton, Florida, V. 1, V. 2, 1985.

Nofziger, D.L., J.R. Williams and T.E. Short, "Interactive Simulation of the Fate of Hazardous Chemicals During Land Treatment of Oily Wastes", RITZ User's Guide, Robert S. Kerr Environmental Research Laboratory, USEPA, Ada, OK, 1987.

Parino, W., et al., "Evaluation and Selection of Models for Estimating Air Emissions from Hazardous Waste Treatment, Storage and Disposal Facilities", GCA Corporation Report No. GCA-TR-82-82-G, USEPA, 1983.

Polcyn, A.J. and H.E. Hesketh, "A Review of Current Sampling and Analytical Methods for Assessing Toxic and Hazardous Organic Emissions from Stationary Source," Journal of the Air Pollution Control Association, V. 35, No. 1, pp. 54-60, 1985.

Schroeder, P.R., J.M. Morgan, T.M. Walski, and A.C. Gibson, "The Hydralic Evaluation of Landfill Performance (HELP) Model", V. 1, EPA/530-SW-84-009, U.S. EPA, 1984.

Shen, T.T. and T.J. Tofflemire, "Air Pollution Aspects of Land Disposal of Toxic Waste", Journal of Environmental Engineering, Division of ASCE, V. 106, No. EEI, pp. 211-266, 1980.

Shih, C.S., and H. Bernard, "An Expert System for Hazardous Waste Site Cleanup, Part I," Hazardous Materials Control, pp. 19-52, 1988.

Spurr, G., and A. Parker, ed., "Meteorological Factors and Dispersion," In Industrial Air Pollution Handbook, London, New York, McGraw-Hill, pp. 123-140, 1978.

Stern, A.C., R.W. Boubel, D.B. Turner, and D.L. Fox, Fundamentals of Air Pollution, (2nd edition), Academic Press, Inc., 1984.

The Netherlands, Ministry of Housing, Planning and the Environment, "Implementation of the Soil Clean-up (Interim) Act", Soil, Water and Chemical Substances Department, Soil Branch, pp. 12, 1983.

U.S. EPA, "Development of Advisory Levels for Polychlorinated Biphenyls (PCBS) Cleanup", EPA/600-6-86/002, U.S. EPA, Washington, D.C., NTIS PB86-232774, 1986.

U.S. EPA, "Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge," Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, Cincinnati, OH, ECAO-CIN-489, 1987.

U.S. EPA, "Development of Risk Assessment Methodology for Municipal Sludge Landfilling," Environmental Criteria and Assessment Office, Cincinnati, OH, ECAO-CIN-485, 1986.

U.S. EPA, Guidelines on Air Quality Models, OAQPS Guidelines Series, Research Triangle Park, 1980.

U.S. EPA, "Mathematical Model Selection Criteria for Performing Exposure Assessments", Groundwater Contaminants from Hazardous Waste Facilities, Draft Technical Support Document, Exposure Assessment Group, U.S. EPA, Washington, D.C, 1986.

U.S. EPA, Office of Environmental Processes and Effects Research, "Simulated Waste Access to Ground Water (SWAG) Data Base".

U.S. EPA, "RCRA Land Disposal Restriction Model", In Guidance on Remedial Actions for Contaminated Soils at CERCLA Sites, CH$_2$M Hill, 1985.

U.S. EPA, "Superfund Exposure Assessment Manual", (Draft), Office of Solid Waste and Emergency Response, U.S. EPA, Washington, D.C., 1987.

U.S. EPA, "User's Manual for the Pesticide Root Zone Model (PRZM)", Release 1, EPA-600/3-84-109. U.S. EPA, Athens, GA, 1984.

U.S. Geological Survey, "Burial Ground Studies at Oak Ridge National Laboratory", Oak Ridge Tennessee.

U.S. Nuclear Regulatory Commission, Earth Sciences Branch, Office of Nuclear Regulatory Research, "Unsaturated Flow and Transport through Fractured Media", Washington, D.C.

Versar, Inc., Air Dispersion Modeling as Applied to Combustion Point Source Evaluations, (Draft), U.S. EPA, Office of Solid Waste, March 1987.

Washington Department of Ecology, "Final Cleanup Policy - Technical Guidelines", 1984.

Yeh, G.T. and D.S. Ward, FEMWATER: A Finite Element Model of Water Flow Through Saturated-Unsaturated Porous Media, ORNL-4927, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1979.

APPENDICES

APPENDIX A

APPENDIX A
Technical Resources
(points of contact for soil and ground water information)

	Ground Water Forum	Engineering Forum
Region 1	John Zannos	John Gallagher
Region 2	Richard Willie Kevin Willis	Richard Kaplan
Region 3	Kathy Davies	Agram "Mike" Fayon Jeff Winegar
Region 4	Mike Towle Bernie Hayes	Harry Harbold Jim Orban
Region 5	Joe Hughart Doug Yeskis	
Region 6	Ruth Izraeli	Deborah Griswold
Region 7	Kathleen O'Reilly Steve Kinser	Steve Kovac
Region 8		Henry Schroeder
Region 9	Jeff Rosenbloom	John Blevins
Region 10	Rene Fuentes	John Kemmerer John Barich
Headquarters	Bernard Zavala Ron Wilhelm	

EPA Laboratory Contacts

Robert S. Kerr Environmental Research Laboratory
Ada, OK

Dick Scalf	FTS 743-2308 (405) 332-8800

Environmental Research Laboratory
Athens, GA

Bob Ambrose	FTS 250-3130 (404) 546-3402 or 3130

For additional contacts see the Ground Water Research Technical Assistance Directory (EPA/600/9-89/048) which can be obtained from the Center for Environmental Research Information/ORD, (513) 569-7391 or the Practical Guide for Assessing and Remediating Cortaminated Sites (Draft May 1989) which can be obtained through Joe Abe, Office of Solid Waste, 475-7371.

APPENDIX B

APPENDIX B

Glossary Of Terms

Adsorption: the attraction of ions or compounds to the surface of a solid; soil colloids adsorb large amounts of ions and water. This process can be reversed and the adsorbed material recovered by the opposite reaction, called desorption or stripping and is estimated using K_d affected by organic content of soil.

Advection: the horizontal movement of mass through a medium.

Biouptake: the uptake of contaminants by biological organisms (plants and animals).

Bulk density: the weight of an object or material divided by its volume, including the volume of its pore spaces. Specifically, the weight per unit volume of a soil mass that has been oven-dried to a constant weight at 105°C.

Clapp - Hornberger constant: a constant in the equation of Clapp and Hornberger (1978) relating to the relative saturation of the soil to the relative conductivity of the soil.[7]

Climatology: study of the characteristic weather of a region, particularly regarding temperature and precipitation, averaged over some significant interval of time.

Conservative substance: A substance that does not undergo reactions in the environment that would either naturally or through interaction with other pollutants cause concentrations to decline.

Darcy velocity: a standard unit of permeability, equivalent to the passage of one cubic centimeter of fluid of one centipoise viscosity flowing in one second under a pressure differential of one atmosphere through a porous medium having an area of cross section of one square centimeter and a length of one centimeter.[1]

Darcy's Law: the relationship that states that the rate of flow of ground water through a porous material is proportional to the pressure driving the water and inversely proportional to the length of the flow path.[12]

Degradation rate (chemical persistency): the rate at which a chemical is broken down in the environment by hydrolysis, photodegradation, or soil metabolism; the length of time that a parent chemical persists in the environment.

Detectable concentration in water: any concentration of a contaminant in water that is greater than or equal to the particular method detection limit.

Diffusion: the spreading out of molecules, atoms, or ions into a vacuum, fluid, or porous medium in a direction tending to equalize concentrations in all parts of the system.[1]

Dilution: thinning down or weakening a compound by mixing with water or other solvents.

Discharge time: the time that would be required for water to move through an aquifer if the aquifer was an open conduit (see discharge velocity).

Discharge velocity: an apparent velocity, calculated from Darcy's law, which represents the flow rate at which water would move through an aquifer if the aquifer were an open conduit.[12]

Dispersion: a system comprised of two phases, one of which is in the form of finely divided particles distributed throughout a bulk substance.

Distance to receptor: the distance from the contaminated soil to a user in the direction of ground water flow.

Distribution coefficient (K_d): represents the partitioning of a contaminant between liquid and solid phases. K_d is a valid representation of this partitioning only if the reactions that cause the partitioning are fast and reversible and only if the isotherm is linear.[13]

Equilibrium: a balanced condition for a particular reversible chemical reaction.

Exposure pathway: the passage of a contaminant from the source of contamination, through the transport media, to the exposure point and receptor.

Exposure point: the point at which human contact with a contaminant occurs, such as a well.

Exposure: human contact with a physical, chemical, or biological agent through dermal absorption, inhalation, or ingestion.

Grain size: size of a soil particle; basis for soil textural classes.

Half-life: the time period in which half the initial concentration of a contaminant is degraded, assuming that the degradation follows first-order or pseudo first-order kinetics.

Heat exchange coefficient: represents the transfer of heat between two materials or substances.

Henry's Law constant: the constant for the partitioning of a pollutant between the vapor and water phases.[24]

Humidity gradient: the rate of decrease of the amount of water vapor in air with distance usually in the direction in which it decreases most rapidly.[17]

Hydraulic conductivity: a coefficient of proportionality describing the rate at which water can move through a permeable medium.[13]

Hydraulic gradient: the change in total head with a change in distance in a given direction; the direction is that which yields a maximum rate of decrease in head.[12]

Hydrolysis: the degradation of a contaminant by chemical reactions involving water or an aqueous solution.

Hydrophobic contaminants: compounds that do not have a strong affinity for water.[1]

Infiltration rate: a soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water.[2]

Inorganic complexation: the attachment of a transition-metal ion to another molecule or ion by means of a coordinate convalent bond.

Ion exchange: substitution of one ion, either positive (cation) or negative (anion), for another of the same charge.

Land use: planned or proposed future use of a site.

Lateral dispersivity: distribution or suspension of fine particles in directions lateral to the flow path of a dispersion medium, such as contaminants in ground water.

Leaching: the removal of materials in solution from the soil by percolating water.[2]

Location: the position of a site with respect to potential migration of contaminants to ground water.

Longitudinal dispersivity: the distribution or suspension of fine particles along the flow path of a dispersion medium, such as contaminants in ground water.

Loss/decay: the degradation of chemicals resulting in a reduction in the concentration of contaminants in soil or ground water.

Mixing rate: the rate that infiltrate and ground water are combined.[20]

Non-toxic threshold level: the "safe" level of a contaminant that is based on a NOEL (no observable effect level) from animal toxicity testing in combination with a human safety factor.

Organic carbon partition coefficient (K_{OC}): soil:water partition coefficient for a contaminant normalized to the soil's organic carbon content.[13]

Organic complexation (chelating): a process in which a metal ion is bound to nonmetal atoms (e.g., nitrogen, carbon, or oxygen) to form a heterocyclic ring having coordinate covalent bonds.

Oxydation: a reaction in which electrons are transferred from one atom to another.

Partition coefficient: a mathematical expression to represent the ratio of a contaminant concentration in each of two phases (e.g., soil: water).

Photolysis: the degradation of a contaminant by chemical reactions catalyzed by light.

Porosity (soil): the volume percentage of the total soil bulk not occupied by solid particles.[2]

Precipitation recharge: the replenishment of ground water from infiltration of precipitation. Quantity measured using a rain gauge and calculating water level changes.[19]

Reduction: the acceptance of one or more electrons from another substance.

Remediation: a measure or solution that resolves a particular problem of a contaminated site.

Retardation: hinder, delay, or slow the progress of contaminant migration to ground water.

Risk assessment: the determination of risks associated with contamination of a site, including exposure assessment, toxicity determinations (hazard assessment), and the determination of exposure pathways.

Saturated zone thickness: The width of the zone in which the voids in the rock or soil are filled with water at pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.[12]

Soil moisture (water) potential: a measure of the difference in the free energy state of soil water and that of pure water. Technically defined as that amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermically an infinitesimal quantity of water from a pool of pure water, at a specified elevation and at atmospheric pressure, to the soil water (at the point under consideration).[2]

Source concentration: the concentration of a contaminant in the soil of a site (i.e., the source of ground water contamination).

Taste and odor thresholds: the lowest concentration of a contaminant that can be detected by taste or odor.

Temperature gradient: the rate of decrease of air, water, or soil temperature with distance, usually in the direction it decreases most rapidly.[17]

Transport rates: the rate of movement of a contaminant in a natural transport medium such as ground water, either as solid particles or in solution, from one place to another.[1]

Transverse dispersivity: the distribution or suspension of fine particles in directions normal to the flow line of a dispersion medium, such as contaminants in ground water.[13] A derived quantity generally obtained by first deciding on a contaminant transport model and then adjusting parameters to match field data.

Unsaturated zone thickness: the width of the zone between the land surface and the water table, including the root zone, intermediate zone, and capillary fringe. Value usually obtained by drilling and analyzing soil cores at various site locations.[12]

Vertical dispersivity: the vertical distribution of fine particles in a dispersion medium, such as contaminants in ground water.

Void fraction: the volume fraction of void space in a sediment or sedimentary rock.[1]

Volatilization: the loss or release of contaminants, in the gaseous state, from soil or ground water to air.

Water solubility: the mass of a compound that will dissolve in a unit volume of water under specified conditions.[13]

APPENDIX C

APPENDIX C
Leachate Extraction Tests

A number of methods for establishing soil cleanup levels make use of a leachate extraction test (e.g., Extraction Procedure (EP) Toxicity, Toxicity Characteristics Leachate Procedure (TCLP)) to determine the fraction of contaminants in the soil that are soluble, and thus have the potential to contaminate ground water. Different approaches have been taken to utilize these test values. One approach is to apply EP Toxicity regulatory levels directly to soil cleanup level determinations. This is done by setting soil cleanup levels at the concentration that would result in leachate concentrations less than the EP Toxicity maximum allowable values. This approach is based on the presumption that if the contaminated soil is not a hazardous waste according to RCRA-established levels, then it has been cleaned up to an acceptable level. However, setting the target level to EP Toxicity levels may not be adequately protective because concentrations of contaminants remaining still have the potential to contaminate the ground water at levels that exceed health-based drinking water standards.

The preferred approach is to use the EP Toxicity or TCLP test as soil leaching tests. The assumption is that the contaminant concentrations found in the laboratory extraction test leachate are equivalent to the concentrations actually leaching from the soil. This could be considered an acceptable application of the leachate extraction test if the cleanup levels attained are comparable to established health-based criteria and the ground water is close to the surface.

The EP Toxicity and TCLP tests are based on a pass-fail hazardous waste evaluation procedure. They were designed as leaching tests for wastes in a municipal landfill, such that the leaching potential of a waste can be determined and then can be disposed of properly. They were not designed to be applied as "soil leaching tests", and, therefore, several inherent limitations exist when using the tests for this purpose. For instance, the tests only address the aqueous phase of water soluble contaminants. Hydrophobic organic chemicals in a soil sample that are sorbed on particles would be removed when the sample is filtered according to the test procedures, and, therefore, would not be detected. An additional assumption of the tests, is that all sorption of contaminants onto soil particles is irreversible. In other words, it is assumed that contaminants which have not become soluble after the extraction procedure is conducted will remain sorbed. Scientific evidence indicates, however, that certain types of sorption are reversible in a natural soil pore water system, but may not be readily desorbed during the extraction procedure. Another limitation is that the laboratory extraction tests have not been validated for use on natural soils that have different chemical and physical properties.

This is a concern because no data are available to ascertain the performance of the test on the wide variety of soil types that exist at Superfund sites. In addition, some contaminants such as solvents, volatile organics or immiscible phase wastes do not depend on water solubility for transport. Because the leachate extraction tests are based on the water solubility of contaminants, test results for these chemicals may not be valid. Another limitation is a result of the filtering step in the extraction procedure. The test assumes that only what passes through a filter is capable of being transported in soil pore water or ground water systems. Filtering, however, can remove from the leachate certain contaminants that are transported by micro particles of organic or mineral origin. Scientific evidence indicates that contaminants can be transported through the soil and ground water in this manner.

The most appropriate use of laboratory leachate tests would be as a first approximation for predicting the chemical composition of leachate systems in the field. The remainder of this Appendix describes some of the tests that are presently available.

Five leachate extraction test procedures are presented here with a brief description of their methodologies and a discussion of their appropriate uses and limitations. These procedures include the Extraction Procedure (EP) Toxicity test, Toxicity Characteristic Leaching Procedure (TCLP), The California Waste Extraction Test (WET) and the American Society for Testing and Materials procedure (ASTM D3987). Also described is a procedure for determining the net acid production or neutralization potential in a waste sample, which can be used to assist in selecting the appropriate leachate extraction test.

EP Toxicity Test - The test was developed by EPA to determine if a solid waste exhibits the EP Toxicity characteristics of a hazardous waste. A solid waste whose extract contains any of the EP Toxicity constituents at concentrations equal to or greater than the designated maximum values, as specified in 40 CFR Part 261.24 Table I, is considered to be EP toxic, and, therefore, is characterized as a hazardous waste.

To obtain the waste extract, the EP Toxicity test procedures are used. The liquid and solid components of a waste sample are separated and the solid portion is added to 16 times its weight of deionized water and agitated for a period of 24 hours. During the agitation period, the pH level of the solution is maintained at 5.0 ± 0.2 with a 0.5N solution of acetic acid, at no more than 4 milliliters of acid per gram of solid for each addition. The temperature is maintained at 20-40°C. After agitation, the leachate solution is filtered from the solid portion, and the liquid extracted from the original sample is added to the leachate solution. These combined liquids then are analyzed for EP Toxicity constituents. (Refer to 40 CFR Part 261 Appendix II for a more detailed description of the EP Toxicity Test procedures.)

The EP Toxicity test is a promulgated procedure with maximum concentration values established for eight metals, four pesticides and two herbicides. Therefore, these constituents would be the ones most appropriate for analysis using this leachate extraction methodology. When using the EP Toxicity test to simulate the degree of leaching that actually would occur from a disposed waste (as opposed to its intended purpose as a pass-fail waste classification test), analysis of additional inorganic and non-volatile organic constituents may be appropriate.

TCLP - This test was developed by EPA to address a Congressional mandate to identify additional characteristics of wastes, primarily organic constituents, that may pose a threat to the environment. It has been promulgated for use in determining specific treatment standards associated with the land disposal restrictions and has been proposed as a replacement for the EP Toxicity test. The procedure involves an 18-hour extraction of a sample and uses a different leaching solution depending on the nature of the waste being tested. For wastes of low alkalinity, an acetic acid/sodium acetate buffer solution at a pH of 5.0 is used for extraction. An acetic acid solution is used for a more alkaline waste. Unlike the EP Toxicity test, the TCLP can be used for volatile waste constituents because a zero headspace extraction vessel can be employed.

This procedure expands the EP Toxicity list of contaminants from 14 to a total of 52. The additional contaminants include 20 volatile organics, 16 semi-volatile organics and two pesticides. The regulatory level for these contaminants are derived from health-based concentration thresholds and compound-specific dilution/attenution factors developed using a ground water transport model. Lastly, note that current regulations are being proposed to modify the TCLP and to expand the list of constituents to be analyzed by this technique. (For a more detailed description of the TCLP, refer to 40 CFR Part 268, Appendix I. The proposed modificaions can be found in 53 FR 18792.)

California Waste Extraction Test (WET) - The WET is used to determine extractable concentrations of toxic constituents in a waste. The acid buffer solution used in the WET is designed to simulate leaching characteristics which may occur in a nonhazardous solid waste landfill. A waste sample is added to a 0.2M sodium citrate solution at pH 5.0 ± 0.1. The solution is then flushed vigorously with nitrogen gas for 15 minutes to remove and exclude atmospheric oxygen from the extraction medium. If volatile substances are to be analyzed, the sample should be added after deaeration with nitrogen to avoid volatilization loss. The sample is agitated for 48 hours and maintained at 20-40°C. The extract then is filtered directly or centrifuged and filtered from the solid portion, and analyzed. (For a complete description of the WET methodology, refer to the California Code of Regulations, Title 22, Division 4, Chapter 30, Section 66700.)

The WET is used to determine leachate constituent concentrations primarily for inorganics, pesticides, herbicides, PCPs and PCBs. The current procedure is not designed to accurately determine extractable concentrations for volatile organics because significant quantities of these constituents would be lost to the air space in the extraction vessel during agitation as well as to the atmosphere during other waste and extract handling phases of the WET. However, the WET could be used for extracting volatile organics provided that a Zero Headspace Extraction vessel is used, such as in the TCLP method.

A citric acid buffer solution is used in the WET to simulate the potentially acidic environment that the waste may be exposed to as well as the acidic leachate generated by the waste itself. In some cases however, it may be appropriate to use deionized water in the WET to more accurately assess the leachability of contaminants in wastes that have no acid generation potential or have sufficient potential to neutralize all the acid formed in the waste. (Refer to the American Society for Testing and Materials (ASTM) procedure for an additional deionized water leachate extraction test method.)

A deionized water extraction also should be used when the extract is to be analyzed for hexavalent chromium. This is because in the presence of the acid buffer, chromium (VI) may be reduced to chromium (III), thus making the analysis for Chromium (VI) invalid. Additionally, deionized water extractions are necessary when analyzing the extract for total dissolved solids or specific conductivity since the acid buffer can interfere with these analyses.

ASTM D3987 Method

The procedure requires a mixture of solid waste and deionized water (Type IV reagent water) and an agitation period of 18 hours at 18-27°C. The mixture ratio used is a volume of test water equal in milliliters to 20 times the weight in grams of waste sample (e.g., 70g sample = 1,400 ml water). After agitation, the leachate solution is separated from the solid phase by filtration and analyzed.

This method has been tested to determine its applicability to certain inorganic components in the solid waste. It has not been tested for applicability to organic and volatile constituents. (For a complete description of ASTM D3987, refer to the 1988 Annual Book of ASTM (American Society for Testing and Materials) Standards, Volume 11.04.)

An appropriate application for this deionized water leachate extraction procedure is for waste samples that have no acid generation potential or have the potential to neutralize acids formed in the waste. Other appropriate applications are if the extract is to be analyzed for hexavalent chromium, total dissolved solids, or specific conductivity.

Net Acid/Base Potential Procedure

The procedure can be employed to determine if an acidic or a deionized water leaching solution should be used to extract the soluble fraction of contaminants in a solid waste sample. It involves the use of analytical procedures to identify the acid generation potential (AGP) and the acid neutralization potential (NP) of a waste. AGP minus NP is a measure of net acid/base potential (Net ABP). A Net ABP value indicates the degree of net acid production or net neutralization potential of a waste. A positive value indicates the likelihood that an acidic leachate will be formed and a negative value indicates that an acidic leachate probably will not be formed. Thus, the results obtained from this procedure can be used to select the appropriate leaching solution and leachate extraction test.

An acidic leaching solution is appropriate for any waste showing a positive Net ABP while a deionized water leaching solution should be used for wastes having a negative Net ABP. (For a complete description of AGP and NP analytical procedures refer to the following: A. Bruynesteyn and D. W. Duncan, "Determination of Acid Production Potential of Waste Materials", Paper for B.C. Research, Vancouver, British Columbia.)

APPENDIX D

APPENDIX D
Methods for Determining K_d Values

The mobilization, volatilization, and transformation reactions of a contaminant in the unsaturated zone are due to the partitioning (adsorption-desorption) of the contaminant to the phases existing in the zone. These phases include soil, water, and vapor (soil gas). Soil physical and chemical properties affect the ability of a chemical to be adsorbed to soil surfaces. Important in governing the extent to which an organic contaminant will be adsorbed are specific aspects of its chemical structure including molecular size, hydrophobicity, molecular charge, organic molecular fragments that undergo hydrogen bonding, the three-dimensional arrangement, interaction of molecular fragments, and molecular fragments that undergo coordination bonding.

The partition coefficient (K_d) mathematically expresses this partitioning. K_d is an equilibrium constant defined as the ratio of the contaminant concentrations in each of two phases (when equilibrium between the two phases has been reached). At this point, adsorption-desorption of a contaminant between the particular phases is at an equilibrium. K_d values are used in modeling contaminant movement through the subsurface. An underlying assumption to using K_d, is that the partitioning process in environmental systems, such as the unsaturated zone, is assumed to reach equilibrium rapidly relative to the movement of water through soil pores.

The most common K_d used is for the partitioning of a contaminant between one of the other phases in the system and water. The majority of methodologies described in this compendium address the partitioning of a contaminant between the soil and water phase (i.e., the soil:water K_d). Therefore, this appendix will focus on the partitioning of contaminants, particularly organic contaminants, between these phases.

Several of the methodologies described in the compendium use both a K_d and a maximum allowable ground water contaminant concentration value to calculate the corresponding soil contaminant concentration. This soil concentration can be used to establish a soil cleanup level. The basic equation used for this determination is:

$$C_{soil} = C_{water} (K_d)$$

where;

C_{soil} = contaminant concentration in soil
C_{water} = contaminant concentration in soil water or ground water
K_d = soil:water partition coefficient

A K_d value can be estimated using a number of sources and techniques that vary from simply obtaining a value from scientific literature to constructing an elaborate laboratory soil column apparatus. The choice of technique depends on the level of accuracy necessary for the soil cleanup level methodology in which it will be applied, the amount and accuracy of required field data, and the availability of time and funding. Several methods for determining K_d values along with a description of their advantages and limitations, are described below.

Literature Sources - The simplest method for acquiring a K_d value for a specific contaminant is to obtain it from a K_{oc} or K_{om} value listed in literature sources. K_{oc} and K_{om} are analogous to K_d, except that the adsorbing material is considered to be the organic carbon (oc) or the organic matter (om) in the soil, respectively, as opposed to the entire soil matrix. By normalizing K_d on the basis of the soil's organic carbon or organic matter content, a great deal of the variation observed among K_d over different soils can be eliminated. Normalized K_d values are expressed as follows:

$$K_d = K_{oc} (oc)$$
$$= K_{om} (om)$$

where;

oc = soil organic carbon content in the soil
om = soil organic matter content in the soil.

The following equation explains the relationship between (om) and (oc) and is assumed to be constant:

$$K_{oc} = 1.724 (K_{om})$$

K_{oc} or K_{om} values can be used directly as the K_d value for a specific contaminant if the necessary soil data are not available, however, a more accurate estimation can be obtained when adjusting the values with the organic matter content of the contaminated soil in question. (The EPA publication, "Evaluating Cover Systems for Solid and Hazardous Waste", EPA SW-867, September 1982, contains a table estimating percent organic matter typically found in soils.) Thus, an estimation for K_d can be determined using these organic matter percentages and the K_{om} value, or using the K_{oc} value adjusted according to the previous equation, as follows:

$$K_d = K_{om}(om) = \frac{K_{oc}(om)}{1.724}$$

The advantages of obtaining K_d values from literature sources is that it is a very fast and inexpensive method. It would be used most appropriately in a situation that required a "quick and dirty" estimation where little field data were available.

Another literature source method for estimating K_ds can be found in a publication entitled The Soil Chemistry of Hazardous Materials, by James Dragun, Ph.D. (Chapter 6, Table 6.4). In the book are listed 14 equations that can be used to estimate K_{oc} or K_{om}. These equations are based on two empirical measurements of organic chemical hydrophobicity: water solubility, and the octanol-water partition coefficient, which are readily available in literature sources for most organic chemicals. The estimation equations were derived on the basis that water is the primary solvent in the soil system. Listed with the equations are the organic chemicals that were used to develop each equation. Also included for each equation is a range of soil organic carbon or organic matter content within which the equations are valid.

The author points out the fact that these equations are not universally applicable to all organic chemicals in all soil systems and should not be used without regard to their limitations (e.g., applicable for contaminants with molecular weights less than 400). These limitations can be found in the text and should be thoroughly reviewed prior to using the equations to determine a K_d value.

Batch Method - Other methods for estimating K_d involve the use of experimental measurements. One is the batch method, in which a soil with a known contaminant concentration is combined with purified water and agitated for a period of time allowing for an equilibrium to be reached. The resulting solution is filtered to remove solids and both the solution and solids are analyzed to obtain the concentration of the contaminant in question. Using these concentrations in the basic K_d equation:

$$K_d = \frac{C_{soil}}{C_{water}}$$

a value can be obtained. The batch experiment also can be conducted by combining a given amount of soil to a solution of known contaminant concentration and agitating until the contaminant concentration in solution no longer decreases. This is the point where it is assumed that an equilibrium condition has been reached.

The batch experiment is considered to be a fairly effective method for determining a K_d, however, it is more reflective of a laboratory-derived value. The agitation technique used to attain equilibrium exposes a larger soil surface area than would be expected under site conditions. Also, the contained system design, where no water is flowing into or out of the system, is not a realistic simulation of actual site conditions. Additionally, the method offers no additional information regarding interstitial fluid movement in a subsurface system.

Column Test Method - Another experimental measurement method for determining K_d is the column test method. One version of this procedure requires a column of contaminated soil of known concentration taken from the field in an undisturbed manner (e.g., Shelby tube) which is used as a flow medium for initially purified water. The soil pore volume for the sample is calculated and a volume of water equaling the soil pore volume is forced through the vertically oriented column under pressure. The effluent is collected and analyzed for the contaminant of concern. The contaminant concentration remaining in the soil after the test is completed is then determined. The result of this analysis and the effluent concentration can be plugged into the basic K_d equation to calculate a value.

The column test procedure offers some advantages over the batch experiment method. Because it is an open flow system and because the soil is not agitated, it more accurately simulates the actual site conditions. Additionally, the column test can be used to obtain other useful information such as the flow velocity and hydraulic conductivity of the soil and transport characteristics of the contaminant.

Instead of using purified water in the previously described procedures, a more appropriate solution would be unsaturated zone ground water upgradient of the contaminated area at the site under investigation. This technique would allow a better simulation of actual site conditions and could potentially increase the accuracy of the results.

Field Measurements - Experimental field measurements also can be conducted to determine K_d values. This requires the use of non-soil-interactive tracers such as tritium, however, this procedure takes a greater amount of time and cost to conduct than laboratory experiments such as the batch and column test methods. Additional information on K_d measurement techniques using radioactive tracers can be found in the EPA report 520/6-78-007, Volume 1, 1978, entitled: "Radionuclide Interactions with Soil and Rock Media."

EPA Experimental Methodologies - Several experimental methodology studies relating to the partitioning of compounds have been and are continuing to be conducted by or through Robert S. Kerr Environmental Research Laboratory (RSKERL) in Ada, Oklahoma, and at other EPA laboratories. One method utilizes breakthrough curves from column studies to determine a soil:water K_d. In this method, breakthrough curves are developed which plot relative concentration versus soil pore volumes.

Another method developed for determining K_d values requires the use of batch isotherms. A contaminant is added to a two-phase system (e.g., soil and water) and equilibrium of the system is reached by tumbling. The phases are separated, each phase is analyzed for the contaminant of concern and the results are used to calculate a K_d value.

RSKERL-Ada has developed a laboratory procedure for determining K_d values in the presence of mobile and immobile organic phases. The procedure was developed as part of the Cont Pro model described in this compendium.

For further information on EPA methodologies for determining K_d, contact Joe Williams (FTS 743-2246) or John Mathews (FTS 743-2233) at RSKERL-Ada.

* * * * *

When using K_d values to determine soil cleanup levels (whether the K_d was obtained from literature values or derived from laboratory or field techniques) it is at best an estimation of the partitioning process. Therefore, the applicability of the chosen method for determining the K_d value to the particular site condition, as well as the advantages and limitations of the method should be given serious consideration. Also important, as emphasized throughout the compendium, is that an increase in the quantity and quality of actual field data used to determine K_d will result in a more reliable K_d estimation.

Solubility and Koc Values For Constituents of Concern

Constituent	Solubility[1] Value (mg/l)	Koc Value (l/mg)
Acenapthene	3.42E+00	4.60E+03
Acenaphthylene	3.93E+00	2.50E+03
Acetaldehyde	1.00E+06	2.19E+00
Acetone	1.00E+06	2.19E+00
Acetonitrile	1.00E+06	2.19E+00
Acrolein	2.10E+05	4.90E-01
Acrylonitrile	7.90E+04	8.50E-01
Aldicarb	6.00E+03	3.65E+01
Allyl Alcohol	5.10E+05	3.17E+00
Aniline	3.40E+04	1.30E+02
Antimoney (Trisulfide)	1.20E+00	5.00E+04
Arsenic (Trioxide)	1.50E+04	5.00E+00
Barium (Hydroxide)	9.35E+04	5.00E+01
Benzene	1.78E+03	8.30E+01
Benzo(A)anthracene	5.70E-03	1.40E+06
Benzo(A)pyrene	3.80E-03	5.50E+06
Benzo(B)fluoranthene	1.40E-02	5.50E+05
Benzotrichloride	5.30E+02	1.39E+02
Benzyl Chloride	3.30E+03	5.07E+01
Bis(Chloromethyl)Ether	2.20E+04	1.20E+00
Bis(2)ethylexyl Phthalate	4.00E-01	2.00E+09
Cadmium (Hydroxide)	2.00E+00	5.00E+02
Carbon Disulfide	2.30E+03	6.18E+01
Carbon Tetrachloride	7.85E+02	4.39E+02
Chlordane	1.85E+00	1.40E+05
Chlordide (Sodium)	2.20E+05	5.00E-02
Chloroacetaldehyde	4.00E+05	3.62E+00
Chlorobenzene	4.90E-02	3.30E+02
Chloroform	8.20E+03	4.40E+01
2-Chlorophenol	2.85E+04	7.30E+01
Chromium VI (Calcium Chromate)	4.40E+05	5.00E+00
Chrysene	1.80E-03	2.00E+05
Copper (Sulfate)	1.10E+05	5.00E+03
Cyanides (Sodium)	3.30E+05	5.00E+00
Cyclohexane	5.50E+01	4.82E+02
Dibenzo(A,H)anthracene	5.00E-04	3.30E+06
1,2-Dichlorobenzene	1.00E+02	1.70E+03
1,4-Dichlorobenzene	7.90E+01	1.70E+03
1,2-Dichloroethane	8.70E+03	1.40E+01
1,1-Dichloroethene	4.00E+02	6.50E+01
1,2-Dichloroethene	7.00E+02	5.90E+01
Dichloromethane	2.00E+04	8.80E+00
1,2-Dichloropropane	2.70E+03	5.10E+01
Dichloropropanols (2,3-1-DL)	1.60E+05	5.99E+00
1,3-Dichloropropene	2.90E+03	2.70E+01

Solubility and Koc Values For Constituents of Concern (continued)

Constituent	Solubility[1] Value (mg/l)	Koc Value (l/mg)
2,4-Dichlorophenol	4.60E+03	3.80E+02
2,6-Dichlorophenol	4.80E+02	1.46E+02
Dimethoate	2.50E+04	1.66E+01
Dimethyl Alkylamines	2.50E+02	2.09E+02
2,4-Dimethylphenol	5.90E+02	9.60E+01
1,3-Dinitrobenzene	4.70E+02	1.48E+02
2,4-Dinitrotoluene	2.70E+02	4.50E+01
Dinoseb	5.00E+01	5.08E+02
Endosulfan	4.00E-01	9.60E-03
Epichlorohydrin	6.00E+04	1.03E+01
Ethylbenzene	1.52E+02	1.10E+03
Ethylene Dibromide (EDB)	4.30E+03	1.40E+01
Ethylene Oxide	1.00E+06	2.19E+00
Fluoranthene	2.60E-01	3.80E+04
Fluorides (Sodium)	1.90E+04	5.00E+00
Formaldehyde	4.00E+05	3.62E+00
Heptachlor	1.80E-01	1.20E+04
Hexachlorobenzene	6.00E-03	3.90E+03
Hexachlorobutadiene	2.00E+00	2.90E+04
Hexachloroethane	5.00E+01	2.00E+04
Hexachlorocyclopentadiene	2.00E+00	4.80E+03
Hexane	1.00E+01	1.23E+03
Hydroquinone	7.00E+04	9.44E+00
Indeno(123-CD)Pyrene	5.30E-04	1.60E+06
Lead (Hydroxide)	1.25E+02	5.00E+03
Lindane	7.80E+00	1.10E+03
Maleic Anhydride	1.63E+05	5.93E+00
Mercury (Oxide)	4.80E+01	5.00E+02
Methanol	1.00E+06	2.19E+00
Methomyl	1.00E+04	2.75E+01
Methyl Chloride	6.50E+03	4.30E+00
Methyl Ethyl Ketone	3.53E+05	3.88E+00
Methyl Isobutyl Ketone	1.70E+04	2.06E+01
Methyl Isocyamate	6.70E+00	1.53E+03
Methyl Methacrylate	2.00E+01	8.40E+02
Molybdenum (Trioxide)	7.10E+02	5.00E+03
Naphthalene	3.20E+01	9.40E+02
Naphthoquinone	2.00E+02	2.37E+02
Nickel (Hydroxide)	8.20E+01	5.00E+02
Nitrate (Sodium)	6.70E+05	5.00E-02
Nitrobenzene	1.90E+03	3.60E+01
4-Nitrophenol	1.60E+04	4.50E+01
Paraldehyde	1.20E+05	7.02E+00
Parathion	2.40E+01	1.00E+04

Solubility and Koc Values For Constituents of Concern (continued)

Constituent	Solubility[1] Value (mg/l)	Koc Value (l/mg)
PCB-1254	3.10E-02	2.95E+04
Pentachloronitrobenzene	7.10E-02	1.87E+04
Pentachlorophenol	1.40E+01	5.30E+05
Phenol	9.30E+04	6.00E+00
Phorate	5.00E+01	3.20E+03
Phthalic Anhydride	6.20E+03	3.58E+01
2-Propanol	1.00E+06	2.19E+00
Pyridine	1.00E+06	2.19E+00
TCDD (Dioxin)	2.00E-04	3.30E+06
1,1,1,2-Tetrachloroethane	2.00E+02	2.37E+02
1,1,2,2-Tetrachloroethane	2.90E+03	1.18E+02
Tetrachloroethene	2.00E+02	3.64E+02
Tetraethyl Lead	8.00E-01	4.94E+03
Thallium (Hydroxide)	2.40E+05	5.00E+02
Toluene	5.35E+02	2.50E+02
Toluene Diamine (TDA)	5.00E+05	3.20E+00
Toluene Diisocyanate (TDI)	0.00E+00	1.55E+00
Toxaphene	5.00E-01	9.64E+02
1,2,4-Trichlorobenzene	3.00E+01	9.20E+03
1,1,1-Trichloroethane	4.40E+03	1.52E+02
1,1,2-Trichlorodethane	4.50E+03	5.60E+01
Trichloroethene	1.10E+03	1.26E+02
2,4,6-Trichlorophenol	8.00E+02	2.00E+03
2,4,6-Trinitrotoluene	2.00E+02	1.60E+03
Vanadium (Pentoxide)	4.50E+03	5.00E+02
Vinyl Chloride	2.70E+03	8.20E+00
Xylenes	1.60E+02	2.68E+02
Zince (Oxide)	1.30E+00	5.00E+02

---

[1] Solubilities for inorganics are based on the compound listed in parentheses and are given in terms of the constituent of interest (e.g., solubility of zinc oxide given as mg/l zinc).

APPENDIX E

U.S. EPA DRINKING WATER STANDARDS, CRITERIA, AND GUIDELINES FOR PROTECTION OF HUMAN HEALTH
All values presented in this table must be confirmed
As of August 1, 1988
(ug/l)

This document provides a summary of information in the Superfund Public Health Evaluation Manual, the Integrated Risk Information System (IRIS) outputs, and other source documents. Only source documents should be referenced in the ROD. For additional information contact your regional coordinator or the Office of Information Resources Management.

Chemical	Practical Quantification Limits (a)	MCL (b)	MCLG (c)	Proposed MCLG(d)	These Columns Must Be Verified by IRIS: Concentration at 10^{-6} Risk Level (e,f)	These Columns Must Be Verified by IRIS: Concentration at RfD Level (e,f)	Water Quality Criteria for Protection of Human Health(g): Ingestion of Drinking Water Only: Threshold Toxicity Protection	Ingestion of Drinking Water Only: 10^{-6} Cancer Risk	Ingestion of Drinking Water and Aquatic Organisms: Threshold Toxicity Protection	Ingestion of Drinking Water and Aquatic Organisms: 10^{-6} Cancer Risk	Ingestion of Aquatic Organisms Only: Threshold Toxicity Protection	Ingestion of Aquatic Organisms Only: 10^{-6} Cancer Risk	ODW Health Advisory(h) Lifetime 70 kg Adult
Acenaphthene	10	-	-	-	-	-	20	-	-	-	-	-	-
Acenaphthylene	10	-	-	-	-	-	-	-	-	-	-	-	-
Acetone	100	-	-	-	-	3500	-	-	-	-	-	-	-
Acrolein	5	-	-	-	-	-	540	-	320	-	780	-	-
Acrylamide	-	-*	-	0	-	-	-	-	-	-	-	-	-
Acrylonitrile	5	-	-	-	0.06	-	-	0.063	0.058	-	-	0.65	-
Alachlor	-	-*	-	0	-	350	-	-	-	-	-	-	-
Aldicarb	-	-*	-	9	-	45.5	-	-	-	-	-	-	10
Aldrin	0.05	-	-	-	-	1.05	-	0.0012	-	0.000074	-	0.000079	-
Anthracene	10	-	-	-	-	-	-	-	-	-	-	-	-
Antimony, total	30	-	-	-	-	14	146	-	146	-	45000	-	-
Arsenic, total	10	50*	-	50	-	-	-	0.025	-	0.0022	-	0.0175	-
Asbestos	-	-*	-	7.0(k)	-	-	-	0.030(k)	-	0.030(k)	-	-	-
Barium, total	20	1000*	-	1500	-	1750	-	-	1,000	-	-	-	1500
Benzene	2	5	0	-	1	-	-	0.67	-	0.66	-	40	-
Benzidine	-	-	-	-	0.0002	-	-	0.00015	-	0.00012	-	0.00053	-
Benzo(a)anthracene	10	-	-	-	-	-	-	j	-	j	-	j	-
Benzo(a)pyrene	10	-	-	-	-	-	-	j	-	j	-	j	-
Benzo(b)fluoranthene	10	-	-	-	-	-	-	j	-	j	-	j	-
Benzo(k)fluoranthene	10	-	-	-	-	-	-	j	-	j	-	j	-
Benzo(g,h,i)perylene	10	-	-	-	-	-	-	j	-	j	-	j	-
Beryllium, total	2	-	-	-	-	175	-	0.0039	-	0.0068	-	0.117	-
alpha-BHC	0.05	-	-	-	-	-	-	0.013	-	0.0092	-	0.031	-
beta-BHC	0.05	-	-	-	-	-	-	0.023	-	0.0163	-	0.0547	-
gamma-BHC (Lindane)	0.05	4*	-	0.2	-	10.5	-	0.017	-	0.0186	-	0.0625	2
Bis-2-chloroethylether	10	-	-	-	0.03	-	-	-	-	0.03	-	1.36	-
Bis(2-ethylhexyl) phthalate	10	-	-	-	50	700	21,000	-	15,000	-	50,000	-	-
Bromodichloromethane	1	100(i)	-	-	-	700	-	-	0.19	-	15.7	-	-
Bromoform	2	100(i)	-	-	-	700	-	-	-	-	-	-	-
2-Butanone (MEK)	10	-	-	-	-	1,750	-	-	-	-	-	-	170
Cadmium, total	1	10*	-	5	-	-	10	-	10	-	-	-	5

Chemical	Practical Quantification Limits (a)	MCL (b)	MCLG (c)	Proposed MCLG(d)	These Columns Must Be Verified by IRIS		Water Quality Criteria for Protection of Human Health(g)						OW Health Advisory(h) Lifetime 70 kg Adult
					Concentration at 10^{-6} Risk Level (e,f)	Concentration at RfD Level (e,f)	Ingestion of Drinking Water Only		Ingestion of Drinking Water and Aquatic Organisms		Ingestion of Aquatic Organisms Only		
							Threshold Toxicity Protection	10^{-6} Cancer Risk	Threshold Toxicity Protection	10^{-6} Cancer Risk	Threshold Toxicity Protection	10^{-6} Cancer Risk	
Carbofuran	-	-*	-	36	-	175	-	-	-	-	-	-	36
Carbon disulfide	5	-	-	-	-	3,500	-	-	-	-	-	-	-
Carbon tetrachloride	1	5*	0	-	0.3	24.5	-	0.42	-	4	-	6.94	-
Chlorobenzene	2	-	-	60	-	-	488	-	488	-	-		300
Chlordane	0.1	-*	-	0	0.027	1.75	-	0.022	-	0.00046	-	0.00048	-
Chloroform	0.5	100(1)	-	-	-	350	-	0.19	-	0.19	-	15.7	-
2-Chloronaphthalene	10	-	-	-	-	-	-	-	-	-	-	-	-
2-Chlorophenol	5	-	-	-	-	-	-	-	-	-	-	-'	-
3-Chlorophenol	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Chlorophenol	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromium (total)	10	50*	-	120	-	-	-	-	-	-	-	-	120
Chromium (hexavalent)	-	-	-	-	-	175	50	-	50	-	-	-	-
Chromium (trivalent)	-	-	-	-	-	35,000	179,000	-	170,000	-	3,433,000	-	-
Chrysene	10	-	-	-	-	-	-	j	-	j	-	j	-
Copper, total	60	1,000*	-	1300	-	-	1,000	-	-	-	-	-	-
Cyanide	40	-	-	-	-	700	200	-	200	-	-	-	154
DDD	0.1	-	-	-	-	-	-	-	-	-	-	-	-
DDE	0.05	-	-	-	-	-	-	-	-	-	-	-	-
DDT	0.1	-	-	-	-	17.5	-	0.0012	-	0.000024	-	0.000024	-
2,4-D	10	100*	-	70	0.01	350	-	-	-	100	-	-	70
DBCP	5	-	-	0	-	-	-	-	-	-	-	-	-
Dibenzo(a,h)anthrancene	10	-	-	-	-	-	-	j	-	j	-	j	-
Dibutylphthalate	2	-	-	-	-	3,500	44,000	-	34,000	-	154,000	-	-
1,2-Dichlorobenzene(o)	2	-*	-	-	-	-	470	-	400	-	2,600	-	620
1,3-Dichlorobenzene(m)	5	-	-	-	-	-	470	-	400	-	2,600	-	620
1,4-Dichlorobenzene(p)	2	75	75	-	-	-	470	-	400	-	2,600	-	75
1,2-Dichloroethane	0.5	5	0	-	0.4	-	-	-	-	0.94	-	243	-
1,1-Dichloroethene	1	7	7	-	0.06	315	-	0.033	-	0.033	-	1.85	7
cis-1,2-Dichloroethene	-	-*	-	70	-	-	-	-	-	-	-	-	70
trans-1,2-Dichloroethene	1	-*	-	70	-	-	-	-	-	-	-	-	70
Dichloromethane	5	-	-	-	5	2,100	-	0.19	-	0.19	-	15.7	-
1,2-Dichloropropane	0.5	-*	-	6	-	-	-	-	-	-	-	-	-
Dichloropropene	5	-	-	-	-	10.5	87	-	87	-	14,000	-	-
Dieldrin	0.5	-	-	-	-	-	-	0.0011	-	0.000071	-	0.000076	-
Diethyl phthalate	5	-	-	-	-	28,000	-	-	350,000	-	1,800,000	-	-
Dimethyl phthalate	5	-	-	-	-	-	350,000	-	313,000	-	2,900,000	-	-
3-3'-Dichlorobenzidine	20	-	-	-	-	-	-	-	-	0.01	-	0.02	-
2,3-Dichlorophenol	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4-Dichlorophenol	5	-	-	-	-	105	3,090	-	3,090	-	3,090	-	-

Chemical	Practical Quantification Limits (a)	MCL (b)	MCLG (c)	Proposed MCLG(d)	These Columns Must Be Verified by IRIS		Water Quality Criteria for Protection of Human Health(g)						UOM Health Advisory(h) Lifetime 70 kg Adult
					Concentration at 10^{-6} Risk Level (e,f)	Concentration at RfD Level (e,f)	Ingestion of Drinking Water Only		Ingestion of Drinking Water and Aquatic Organisms		Ingestion of Aquatic Organisms Only		
							Threshold Toxicity Protection	10^{-6} Cancer Risk	Threshold Toxicity Protection	10^{-6} Cancer Risk	Threshold Toxicity Protection	10^{-6} Cancer Risk	
2,5-Dichlorophenol	-	-	-	-	-	-	-	-	-	-	-	-	-
2,6-Dichlorophenol	10	-	-	-	-	-	-	-	-	-	-	-	-
3,4-Dichlorophenol	-	-	-	-	-	-	-	-	-	-	-	-	-
2,4-Dimethylphenol	5	-	-	-	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	0.2	-	-	-	-	-	-	0.11	-	0.11	-	9.1	-
Dioxane	150	-	-	-	-	-	-	-	-	-	-	-	-
1,2-Diphenylhydrazine	-	-	-	-	0.05	-	-	0.046	-	0.042	-	0.56	-
Endosulfan	0.1	-	-	-	-	1.75	138	-	74	-	159	-	-
Endosulfan sulfate	0.5	-	-	-	-	-	-	-	-	-	-	-	-
Endrin	0.1	0.2	-	-	-	-	1	-	1	-	-	-	0.32
Epichlorohydrin	-	-*	-	0	3	70	-	-	-	-	-	-	-
Ethylbenzene	2	-*	-	680	-	3,500	2,400	-	1,400	-	3,280	-	680
Ethylenedibromide	5	-*	-	0	-	-	-	-	-	-	-	-	-
Ethyleneglycol	-	-	-	-	-	70,000	-	-	-	-	-	-	7000
Fluoranthene	10	-	-	-	-	-	188	-	42	-	54	-	-
Fluorene	10	-	-	-	-	-	-	-	-	-	-	-	-
Halomethanes	-	0.10	-	-	-	-	-	0.19	-	0.19	-	15.7	-
Heptachlor	0.05	-*	-	0	0.008	17.5	-	0.011	-	0.00028	-	0.00029	-
Heptachlor epoxide	1	-*	-	0	0.004	0.455	-	-	-	0.00028	-	0.00029	-
Hexachlorobenzene	0.5	-	-	-	-	-	-	0.021	-	0.00072	-	0.00074	-
Hexachlorobutadiene	5	-	-	-	0.5	70	-	0.45	-	0.45	-	50	-
Hexachlorocyclopentadiene	5	-	-	-	-	245	206	-	206	-	14,800	-	-
Hexachloroethane	0.5	-	-	-	3	35	-	-	1.9	-	-	8.74	-
Hexane	-	-	-	-	-	-	-	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	10	-	-	-	-	-	-	-	-	-	-	-	-
Iron, total	-	300	-	-	-	-	-	-	-	-	-	-	-
Isophorone	10	-	-	-	-	-	5,200	-	5,200	-	520,000	-	-
Lead, total	10	50	-	20	-	-	50	-	50	-	-	-	-
Manganese, total	-	50	-	-	-	-	-	-	50	-	100	-	-
Mercury (alkyl)	2	-	-	-	-	-	-	-	-	-	-	-	-
Mercury (inorganic)	-	2*	-	3	-	-	10	-	0.144	-	0.146	-	1.1
Methoxychlor	2	100*	-	340	-	-	-	-	100	-	-	-	340
2-Methyl-4-chlorophenol	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Methyl-4-chlorophenol	-	-	-	-	-	-	-	-	-	-	-	-	-
3-Methyl-6-chlorophenol	-	-	-	-	-	-	-	-	-	-	-	-	-
4-Methyl-2-pentanone (MIBK)	5	-	-	-	-	1,750	-	-	-	-	-	-	-
4-Methylphenol	10	-	-	-	-	-	-	-	-	-	-	-	-
Nickel, total	50	-	-	-	-	700	15.4	-	13.4	-	100	-	150
Nitric oxide	-	-	-	-	-	3,500	-	-	-	-	-	-	-
Nitrobenzene	10	-	-	-	-	17.5	19,800	-	19,800	-	-	-	-

Chemical	Practical Quanti-fication Limits (a)	MCL (b)	MCLG (c)	Proposed MCLG(d)	These Columns Must Be Verified by IRIS: Concentration at 10^{-6} Risk Level (e,f)	These Columns Must Be Verified by IRIS: Concentration at RfD Level (e,f)	Water Quality Criteria for Protection of Human Health(g): Ingestion of Drinking Water Only: Threshold Toxicity Protection	Ingestion of Drinking Water Only: 10^{-6} Cancer Risk	Ingestion of Drinking Water and Aquatic Organisms: Threshold Toxicity Protection	Ingestion of Drinking Water and Aquatic Organisms: 10^{-6} Cancer Risk	Ingestion of Aquatic Organisms Only: Threshold Toxicity Protection	Ingestion of Aquatic Organisms Only: 10^{-6} Cancer Risk	ODW Health Advisory(h) Lifetime 70 kg Adult
n-Nitrosodimethylamine	10	-	-	-	-	-	-	0.0014	-	0.0014	-	16	-
n-Nitrosodiethylamine	10	-	-	-	-	-	-	0.0008	-	0.0008	-	1.2	-
n-Nitrosodi-n-butylamine	10	-	-	-	0.006	-	-	0.0064	-	0.0064	-	0.587	-
n-Nitrosopyrrolidine	10	-	-	-	0.02	-	-	0.016	-	0.016	-	91.9	-
n-Nitrosodiphenylamine	10	-	-	-	7	-	-	7.0	-	4.9	-	16.1	-
Oxamic acid	-	-	-	-	-	-	-	k	-	-	-	-	-
PCB's	50	-*	-	0	-	-	-	0.013	-	0.000079	-	0.000079	-
PAHs	-	-	-	-	-	-	-	0.0031	-	0.0028	-	0.031	-
Pentachlorobenzene	10	-	-	-	-	28	-	-	74	-	85	-	-
Pentachlorophenol	5	-*	-	220	-	1,050	1,010	-	1,010	-	-	-	220
Phenanthrene	10	-	-	-	-	-	-	-	-	-	-	-	-
Phenol	1	-	-	-	-	1,400	3,500	-	3,500	-	-	-	-
Pyrene	10	-	-	-	-	-	-	-	-	-	-	-	-
Selenium, total	20	10*	-	45	-	-	10	-	10	-	-	-	-
Silver, total	70	50*	-	-	-	105	50	-	50	-	-	-	-
Styrene	1	-	-	140	-	7,000	-	-	-	-	-	-	140
2,3,7,8-TCDD	0.005	-	-	-	-	-	-	1.8e-7	-	1.3e-8	-	1.4e-8	-
Tetrachloroethene	0.5	-*	-	0	-	350	-	0.88	-	0.80	-	8.85	10
1,1,2,2-Tetrachloroethane	0.5	-	-	-	0.175	-	-	0.17	-	0.17	-	10.7	-
2,3,4,6-Tetrachlorophenol	10	-	-	-	-	1,050	-	-	-	1	-	-	-
Thallium, total	10	-	-	-	-	-	17.8	-	13	-	48	-	-
Toluene	2	-*	-	2,000	-	10,500	15,000	-	14,300	-	424,000	-	2,420
Toxaphene	2	5*	-	0	-	-	-	0.026	-	0.00071	-	0.00073	-
2,4,5-TP	2	-*	-	-	-	-	-	-	-	10	-	-	52
1,2,4-Trichlorobenzene	10	-	-	-	-	700	-	-	-	-	-	-	-
1,1,1-Trichloroethane	5	200	200	-	-	3,150	19,000	-	18,400	-	1,030,000	-	200
1,1,2-Trichloroethane	0.2	-	-	.-	0.6	7,000	-	0.60	-	0.6	-	41.8	-
Trichloroethene	1	5	0	-	3	-	-	2.8	-	2.7	-	80.7	-
2,4,5-Trichlorophenol	10	-	-	-	-	3,500	-	-	2,600	-	-	-	-
2,4,6-Trichlorophenol	5	-	-	-	1.75	-	-	1.8	-	1.2	-	3.6	-
Vanadium	40	-	-	-	-	315(l)	-	-	-	-	-	-	-
Vinyl chloride	2	2	0	-	0.015	-	-	2	-	2.0	-	525	-
Xylene	5	-*	-	440	-	350	-	-	-	-	-	-	400
Zinc, total	20	5,000	-	-	-	7,350	5,000	-	-	-	-	-	-

---

a. Source: 52 FR 25947. Practical quantification limits presented are for standard analytical methods. It may be appropriate to use different analytical methods to achieve lower quantification limits in some cases.
b. 40 CFR 141 and 143.
c. 40 CFR 141.50.
d. 50 FR 46936; November 13, 1985.
e. Integrated Risk Information System database.
f. Assuming drinking water ingestion of 2 liter/day and body weight of 70 kg.
g. 45 FR 79318-79379; November 28, 1980.
h. U.S. EPA, Health Advisories, March 1987.
i. Based on the standard for total trihalomethanes of 100 ug/l.
j. Based on criteria for polycyclic aromatic hydrocarbons (PAHs).
k. Million fibers/liter.
l. For vanadium pentoxide.
* MCL will be proposed in the Federal Register in 1988. MCLs will also be proposed for aldicarb sulfoxide, aldicarb sulfone, atrazine, and dibromochloropropane.

APPENDIX F

APPENDIX F

Site Name: Matthews Electroplating, VA

Site Description: The 1.7-acre site is located in Roanoke County, Virginia, approximately two miles west of Salem. Between 1972 and 1976, two buildings on the site housed an automobile bumper electroplating operation. Ground water sampling in 1975 confirmed that a plant well and a nearby church well were heavily contaminated with hexavalent chromium. Shortly thereafter the owners of the site declared bankruptcy. In 1982 an offsite ground water investigation revealed that 10 local residental wells also had been affected by chromium contamination. Two areas onsite were identified as having moderate soil contamination but it was concluded that the chromium in these areas were adsorbed to the soil. To control further runoff or leaching contamination, the new owners performed some surface cleanup and a clay cover was placed over a small area of the site where chromium wastes had been discharged.

Waste Description: The concentrations of total chromium found onsite were as high as 11,500 ug/l in ground water and 2,998 mg/kg in soils.

Target Cleanup Level Methodology: The RI/FS was completed in 1983, after which a waterline from the nearby municipal water distribution system was extended to approximately 30 nearby homes. The results of the RI indicated that most of the chromium leaching from the soil had reached the ground water prior to the placement of the clay cap in 1977. The highest chromium concentrations in residental wells were encountered at the beginning of the ground water and soil sampling in 1975-1976 and had decreased significantly since that time. The maximum concentration of chromium in groundwater had decreased from 11,500 ug/l in 1976 to .192 ug/l in 1981. Since the levels of chromium were expected to decrease further over time as a result of ground water movement and dilution, a ground water remedy was deferred at that time. To determine if further remedial actions were necessary a full assessment of the extent of the contaminant plume was conducted.

EPA conducted post-remediation sampling in 1987 for both ground water and soil. The results of the sampling showed chromium levels had decreased to a point that no longer posed a threat to public health or the environment. As a final measure, several open drums were removed and two tanks were excavated from the site. Based on the sampling results and prior response activities no further action was recommended. The State of Virginia has agreed to conduct post deletion monitoring of the existing residential wells for a period of three years.

✩ U.S. GOVERNMENT PRINTING OFFICE: 1989-748-159-00366